Asian Development Bank
Energy Efficiency Support Project

Level II Training Programme on Energy Efficiency and Environment Improvement in Fertilizer Industry

21–23 January 1998

Sponsored by

Asian Development Bank

The Industrial Credit and Investment Corporation of India Limited

Organized by

teri

Tata Energy Research Institute

Contents

Fertiliser Industry-A Broad Overview

Dr S Nand
Fertiliser Association of India (FAI), New Delhi

Fertiliser Industry-A Broad Overview

1.0 Introduction

Fertiliser plants are highly energy intensive and a major consumer of hydrocarbons in India. The paper presents the energy consumption scenario in Indian fertiliser industry. The potential and approach for energy saving in various fertiliser plants have been outlined. Some of the measures recently implemented in ammonia and urea plants are highlighted.

Fertiliser industry is intimately related to Indian Agriculture. The development of fertiliser sector in India has not only contributed to the growth of the agricultural sector but also to industrialisation of the country. Indigenous production of fertilisers has come a long way since the commissioning of the first large size ammonium sulphate plant at Sindri in 1951. The fertiliser industry reached a landmark when it achieved about 11.2 million tonnes nutrient production during 1996-97. Today, the industry is not only an essential link in the food chain, but also has made its impact on the national economy. Despite a leap forward in fertiliser production, there continues to be a gap in consumption and production which is filled up with imported material. The gap was 2.2 million tonnes of N and P during 1996-97. The total requirement of potassic fertilisers is imported showing that there is pressing need to increase the domestic fertiliser production capacity.

Production of nitrogenous fertilisers includes ammonium sulphate, ammonium chloride, calcium ammonium nitrate, urea and NP/NPK complex fertiliser products. Phosphatic fertilisers production consists of SSP, DAP and NPK fertiliser products. In India, urea and DAP are the major products for nitrogen and phosphatic supply respectively. Capacity and production of various fertiliser products and intermediates during 1996-97 are given in Table 1.

Table 1. Capacity and Production of Fertiliser Products and Intermediates (1996-97)

(Million MT)

Intermediate/Product	Capacity	Production
Ammonia	11 78	10 20
Sulphuric Acid	6 75	2 86*
Phosphoric Acid	0 73	0 39
Urea	17 07	15.63
Ammonium Chloride (ACl)	0.13	0 12
Calcium Ammonium Nitrate (CAN)	0.94	0 39
Ammonium Sulphate (AS)	0 89	0 67
Single Super Phosphate (SSP)	5.93	3 14
Diammonium Phosphate (DAP)	2 48	2 77
Complex Fertilisers (NP/NPKs)	3 69	3 60

* *Data for 1995-96*

Fertiliser production and application constitute the major part in the energy consumption of agriculture sector. The manufacture, packing, transport and application of 1 kg of nitrogenous fertiliser require approximately 2 kg of fossil fuel and those of phosphatic fertilisers around 3.3 kg of fossil fuel. Obviously, production of nitrogenous fertilisers is more energy intensive. Fertiliser plants accounted for 40 per cent of natural gas, 70 per cent of naphtha and 26 per cent of fuel oil consumption in the country during 1995–96.

In the light of rapid technological developments, various options for revamping and retrofitting the existing plants are available to reduce the energy consumption. The specific energy conservation measures available and implemented are discussed in the paper

2.0 Ammonia Plant

Ammonia is the major intermediate for production of nitrogen as well as complex fertilisers. Its production constitutes the major part of energy required for production of final products (about 85 per cent in urea). India produced a total of 10.2 million tonnes of ammonia in 1996–97.

There are about 40 medium to large size ammonia plants using coal, fuel oil, naphtha and natural associated gas as feedstock in the country. The choice of feedstock is dictated by the availability of energy resources from time to time. Development of ammonia industry in India can be divided into three phases. In the first phase, plants were of smaller size (less than 600 TPD) and used reciprocating compressors. These plants were based on a variety of feedstocks viz. lignite, fuel oil, naphtha, natural gas, coke oven gas, electrolysis etc. Introduction of centrifugal compressors for ammonia production initiated the installation of higher capacity single stream plants in the second phase. Therefore, a number of 600 and 900 TPD plants were installed in 70's. Eighties marked the third phase of ammonia industry by setting up of modern 1350 TPD plants using natural gas as feedstock and incorporating the developments in production technology. The latest generation of plants during last four years have incorporated the advances in materials, process design, equipment design and fabrication techniques, catalyst, etc. These plants have achieved the ever lowest energy consumption per tonne of ammonia.

Feedstockwise installed capacity and production of ammonia in 1996–97 is given in Table 2. The better feedstock and process technologies together with improved operation and maintenance practices, scaling up of the plants, revamping/retrofitting for removal of equipment and design deficiencies, installation of captive power plants etc. have resulted in significant improvement in energy consumption (Table 3). There has been simultaneous reduction in downtime in key sectors of the plants. The downtime due to mechanical breakdown for a 13 year period for ammonia plants is shown in Table 4. It shows that downtime due to mechanical failure came down to 19.3 days/plant/year for the 1990-93 period from 39.3 days/plant/year during 1980-84 period.

Table 2. Share of Feedstocks in Capacity and Production of Ammonia Plants (1996-97)

Feedstock	Capacity (in percentage)	Production (in percentage)
Gas	53.9	60.8
Naphtha	26.4	23.6
Fuel Oil/LSHS	14.7	14.4
Coal	5.0	1.2

Table 3. Average Energy Consumption of Ammonia Production in India

Year	Capacity Utilisation (%)	Energy (G.Cal/MT)
1979-80	63	14.8
1985-86	72	13.7
1987-88	76	12.5
1989-90	82	11.8
1991-92	86	11.6
1994-95	88	11.0
1995-96	94	11.0
1996-97	90	10.9

Table 4. Downtime in Ammonia Plants due to Mechanical Failures

Period	Downtime days/plant/year
1980-84	39.3
1984-87	29.8
1987-90	24.4
1990-93	19.3

Production of ammonia is a multistage process involving high temperature and pressure reactions and various unit operations. The total process can be segregated into three main stages-gas making, gas purification and ammonia synthesis

2.1 Gas Making

In gas making, primary reforming is the major energy consumer. Reformers in old plants have about 85 per cent thermal efficiency which has been improved to 93 per cent in recent reformers.

The increase in efficiency has been possible due to preheating of combustion air, low stack temperature, less heat loss through insulation of reformer box and excess air control. There are several other options available to improve the primary reformer efficiency. For example, reduction in steam-carbon ratio would result in reduction in pressure drop and reduced firing. Use of superior tube metallurgy allows use of thin walled reformer tubes and hence increased catalyst loading. This would result in higher reforming capacity and reduction in specific energy consumption. Feed gas saturation and use of gas turbine for process air compressor alongwith use of exhaust as pre-heated combustion air can result in saving of process steam and reformer fuel saving. In another energy saving measure, part of the reforming load can be shifted to the secondary reformer which is thermally more efficient.

A naphtha based plant debottlenecked its primary reformer by increasing the catalyst volume in reformer tubes. The tubes metallurgy was changed from HK 40 to Manurite 36X with wall thickness reduction of about 4 mm. As a result of this, the plant capacity was debottlenecked by more than 20 per cent and energy reduction of about 0.9 G Cal/MT was achieved. Reformer tubes of improved material have been installed in a number of other plants.

At IFFCO Aonla the flue gas temperature was brought from 180°C to 165°C by providing additional air preheater. This can be further brought down to even lower than 150°C. Though IFFCO Aonla derived a small benefit of 1.18 G Cal/hr energy, other plants where the flue gas temperature is much higher (>200°C) stand to benefit substantially by recovering the sensible heat of flue gases. There are, of course, limitations of space and engineering in locating additional heat recovery systems or increasing the size of existing ones.

The three latest plants commissioned in 1997 and have installed gas turbines for driving the process air compressors.

2.2 *Gas Purification*

The existing CO-Shift section can be modified to provide an extra catalyst in the case of high steam dry gas ratio. The CO slip can be brought down to 0.05 per cent (dry) resulting H2 saving in methanator. This would result in lower heat requirements for regeneration, higher capacity in absorption and regeneration, lower CO_2 slip etc. RCF switched to MDEA CO_2 removal system in their Trombay I plant. Change of tower internals, and packing can be carried out to improve the absorption and regeneration efficiencies. Operation parameters like ratio of semi-lean to lean solution, recirculation rate etc. can be optimised to achieve the lowest energy consumption in this section.

Synthesis gas can be further purified by molecular sieves in addition to methanation step. The lower level of CO_2 and moisture in make up synthesis gas will give reduced refrigeration load and higher per pass conversion.

Carbon monoxide present in the LT outlet gas can be selectively oxidised to carbondioxide by Selectoxo process. Only traces of CO goes to the methanator for conversion to methane. This saves valuable hydrogen and methane content in the synthesis loop. Thus more synthesis gas is obtained from the same feedstock and there is reduction in purge from synthesis loop. Saving in energy is determined by the CO slip from LT. Madras Fertilisers implemented the scheme and achieved 90 per cent conversion of CO. This resulted in energy saving of 0.29 G Cal per tonne of ammonia.

2.3 Ammonia Synthesis

The synthesis loop is purged in order to avoid the build-up of inerts like methane and argon. The hydrogen gas lost with purge gas can be recovered and fed back to synthesis loop saving 0.2 G Cal/MT. Several plants like IFFCO Kalol, IFFCO Phulpur, GSFC Baroda, SFC Kota, MCFL Mangalore, KRIBHCO Hazira, IFFCO Aonla, NFL Vijaipur, RCF Trombay, etc. added the purge gas recovery (PGR) units to their ammonia plants. New plants like NFCL Kakinada and CFCL Gadepan have incorporated PGR units at the design stage itself.

Reduction in synthesis pressure results in savings of energy in compression. With the development of low temperature and low pressure catalyst, it is possible to achieve relatively high conversion at low pressure. The pressure drop across the converter can be reduced with radial gas distribution in catalyst bed. The improved ammonia syn converters generally incorporate interbed heat exchanger instead of quench type converter for better thermal efficiency. The existing plant can save energy of the order of 0.2-0.35 G Cal/MT with the revamp/change of converters.

MFL replaced their original chemico axial flow converter with the Topsoe S-200 radial converter achieving an energy saving of 0.29 G Cal/MT. The new converter is designed for operating pressure of 180-190 kg/cm$_2$ compared to 232 kg/cm$_2$ of chemico converter.

In a 22 year old naphtha based plant, the Topsoe S-100 converter was revamped with S-200 basket in 1992. It enhanced the production capacity of loop by more than 150 TPD and the loop pressure was reduced from 310 to 270 kg/cm$_2$. This change along with other revamp measures and change of almost all the catalysts effected an energy saving of about 0.4 G Cal/MT. A number of other plants like NFL Bhatinda, NFL Panipat,etc have changed to S-200 converters recently.

KRIBHCO Hazira, IFFCO Phulpur and Kalol plants have changed the internals of their Kellog converter with Ammonia-Casale radial- axial baskets. The converter pressure drop is reduced from 4 to 3 kg/cm$_2$ and energy savings is of the order of 0.2 G Cal/MT. The new catalyst used in all the revamped converters is highly active with size of 1.5-3.0 mm as compared

to the 6-10 cm size catalyst before revamp, resulting in higher conversion per pass. A number of other plants like RCF Trombay V and CFL-Vizag have also changed the converter internals from axial to radial axial flow.

2.4 Computer Control and Optimisation

Computer control of critical parameters in ammonia plant provides another opportunity for saving energy and increasing production. Some of the parameters which can be put on control are air-fuel ratio, steam carbon ratio, methane slip from secondary reformer, H_2/N_2 ratio in synthesis gas, purge rate, synthesis converter quench distribution etc. With the help of process control models and multivariable control methods, a computer can maintain the plant in an operating mode to minimise energy consumption and/or maximise plant production. Computer control has been made possible by the instalation of distributed digital control (DDC) system and optimizers in the plants The investment could vary from a few crores to several crores of rupees depending on the number of parameters to be optimised and controlled and level of instrumentation in the existing plant.

RCF Thal had installed advanced control system for automatic control of four critical parameters viz. steam/carbon ratio, H_2/N_2 ratio in make up gas, inert level in syn loop and reformer firing control These plant parameters are continuously monitored, optimum values of set points are calculated and fed to the controllers with DCS interface Thus optimum plant conditions are maintained and 1-2 per cent savings in energy consumption are obtained. KRIBHCO, Hazira installed process optimizers separately on the two ammonia plants. One of them works in advisory mode and the other like Thal in close loop with the plant controllers.

3.0 Urea Plant

There are 37 urea plants operating in the country varying in sizes from 300 TPD to 2200 TPD using the single prill tower The technologies used are total recycle, modified recycle and ammonia CO_2 stripping supplied by Montedison, Stamicarbon, Mitsui-Toatsu, Snamprogetti and others

Production of urea is a high pressure and moderate temperature reaction between ammonia and carbondioxide. About 80 per cent of energy required for urea production is drawn from ammonia Hence reduction and prevention of ammonia losses in the plant helps in reduction of energy consumption. There are a number of developments which help reduce ammonia and utility consumption in urea production.

3.1 Heat Recovery

Conventional total recycle process was replaced by modified total recycle process technology where the heat of condensation of unconverted ammonia and CO_2 generated in HP decomposition stage is usually recovered as LP steam. With the advent of stripping technology, carbamate decomposition and condensation are carried out at synthesis pressure. It helps in efficiency of operation and energy reduction. There are about 17 urea plants in India based on total recycle process without heat recovery. The existing plants can be revamped with energy efficient technologies like ACES, IDR, SRR and UTI processes. MFL revamped its urea plant with UTI heat recycle process.

3.2 High Efficiency Reactor

Conversion in urea reactor can be improved by changing the trays of the urea reactor. This in turn results in higher production and energy saving. One of the relatively new urea plant is able to save 0.03 G Cal/MT urea with urea reactor trays of improved design.

3.3 Ammonia Losses

The average specific ammonia consumption of Indian urea plants is 587 kg. The specific ammonia consumption of the latest plants is as low as 576 kg per tonne urea. Several old plants offer significant scope for improvement on this front. A reduction of 10 kg in average ammonia consumption will translate into saving of about 160,000 MT ammonium per annum or almost Rs.100 crore justifying the investment in modernisation of Indian urea plants.

Ammonia efficiency has been significantly improved with new technologies where specific consumption of 575 kg/MT ammonia can be achieved which is close to stoichiometry figure of 565 kg. The total loss of ammonia is reflected in the form of ammonia and urea emanating as gaseous and liquid effluent continuously or intermittently from various sections of the plant such as the vacuum section, inert washing column, prilling tower etc besides spillages and leakages Ammonia and urea losses through waste water can be reduced by the installation of urea hydrolyser- stripper. Lost ammonia and urea are recovered and recycled back to the system. This not only improves the efficiency but also helps in pollution abatement. Several existing plants viz IFFCO-Phulpur, Kalol; FACT-Cochin, NFL-Nangal etc.have added urea hydrolyser-stripper to their facilities. All the new plants have the urea hydrolyser-stripper right from the beginning.

As in the ammonia plant, critical parameters in urea plants like ammonia-CO_2 ratio in the reactor, the carbamate recycle concentration and reactor temperature can be put on automatic control, allowing the plant to operate under the most stable and optimum conditions.

4.0 Utilities

4.1 *Steam Network*

Ammonia plant generates a large amount of surplus heat which is recovered as steam or gas to gas heat exchange. A large amount of steam is required as process steam and to drive the large compressor turbines. Therefore, efficient design of steam network can improve the thermodynamic efficiency of the plant. With a propely designed steam network system, the ammonia plant can be made practically independent of imported power. Figure 1 shows the steam balance for a typical modern 1350 TPD gas based ammonia plant. The combined waste heat from R G boiler, converter gas boiler and synthesis boiler is first superheated in superheater on flue gas duct to 442°C and finally in an auxiliary fuel fired boiler superheater to 515°C. The high pressure HP steam is utilised on synthesis compressor drive in back pressure turbine and medium pressure steam is extracted. The MP steam is utilised as process steam and driving process air compressor and a number of HP pumps and blowers. Efficiency of steam turbines and compressors is an important factor in the overall energy consumption. Upgradation of inefficient steam turbines has been carried out by IFFCO Phulpur anad is proposed by RCF Trombay and Thal

Captive power plants at site can adopt either cogeneration or combined cycle configuration which offer high thermal efficiency of 40-45 per cent in power generation. Gas based plants have adopted gas turbines with waste heat recovery from exhaust gases to meet the power and steam requirement of ammonia and urea plants in an optimum manner. This enables the most efficient use of fuel with an efficiency of 80-90 per cent.

4.2 *Boiler Efficiency*

Fertiliser production facilities have package boilers to fulfil the steam requirement for process steam, process heating and steam drives. Steam generation efficiency of these boilers can be improved by more efficient burners, control of excess air and micro-processor based instrumentation. Fluidized bed coal boiler gives better thermal efficiency especially with high ash coals

NFL Bhatinda and Panipat have installed the zirconia cell type on line O2 and CO analysers in the flue gas path. It has helped in controlling excess air required for combustion. Investments are not very large and the payback period is less than a year with energy saving of 0.15 G Cal/MT ammonia at Panipat.

An advanced model of coal burner with split coal nozzles has been installed in the coal fired boilers at NFL Bhatinda and IFFCO Phulpur. These nozzles supplied by BHEL create a new vortex pattern within the combustion zone ahead of the burner tips which helps to achieve better combustion and marked reduction in unburnt carbon.

4.3 Other Measures

There are numerous smaller but important measures available for considerable energy savings. For example a number of units have replaced their aluminium casted cooling tower fans with FRP fans of better aerodynamic design to achieve power savings and some others also propose to do the same. FACT Cochin installed a hydraulic turbine in CO_2 section where the solution is let down from 23 to 1.5 ATA. This would produce electricity of 420 KW. The payback period is estimated to be around 3 years. Major energy saving measures implemented recently are given in Table 5.

Table 5. Typical Energy Saving Schemes Implemented

Measure Adopted	Energy Saving (G Cal/MT ammonia)
Change of reformer tubes, all catalysts, change of syn. converter internals etc.	0 4
Additional air heater to bring down flue gas temperature from 180oC to 165oC	0 02
Selective oxidation of CO at LT outlet by Selectoxo process	0 29
Replacement of syn converter with radial flow converter	0 25-0 29
Replacement of syn converter internals with radial or radial-axial flow	0.10-0 25
Installation of O2 and CO analysers	0 15
Urea Hydrolyser	not quantified

5.0 Conclusion

Indian Fertiliser plants are of various vintages using a spectrum of technologies and feedstocks. These offer ample scope for further improvement in their energy efficiency by revamping/retrofitting for energy savings and/or increasing capacity. Energy saving measures offer good investment opportunities with attractive payback period. Of course, the feasibility of these measures has to be established in individual plants Given the right policy environment, Indian fertiliser plants can substantially improve their energy efficiencies.

Bibliography

- Mudahar, M.S. and Hignett, T.P., "Energy and Fertiliser", IFDC, Muscle Shoals, USA, Technical Bulletin T-20, 1982.
- Joharapurkar, V.R., "Modernising Old Urea Plants", FAI Annual Seminar Proceedings, SIV 3, 1986.
- Shah, M.N. and Cassata, J.R., "Ammonia Plant Retrofits", FAI Annual Seminar Proceedings, SII 1, 1986.
- "Control Systems and Simulation in the Nitrogen Fertiliser Industry", Nitrogen No.169, 36, 1987.
- Catachpole, S J and Pinto A., "Energy Conservation in Ammonia Plants", FAI Proceedings, R&D 11, 1987.
- Nand, S. "Energy Efficiency of Sulphuric Acid Plant", Energy Management 11(3) 189, 1987.
- "Energy Manaagement in Fertiliser Industry", Proceedings of FAI Workshop, August, 1990.
- "Modelling, Simulation and Process Optimization", Special Issue of Fertiliser News, June, 1991.
- Nand, S. and Rao, P.Lokeswara, "Higher Productivity Through Improved Maintenance", Fertiliser News 39(12) 27, 1994.
- Nand, S. and Mitra N., "Better Maintenance Enhances Productivity and Savings in Energy", Fertiliser News 42(12) 17, 1997.
- Malhotra A. and Leblanc,J.R., "Ammonia 2000 Kellog KAAP/KRES Technology", FAI Annual Seminar Proceedings, SII-3, 1996

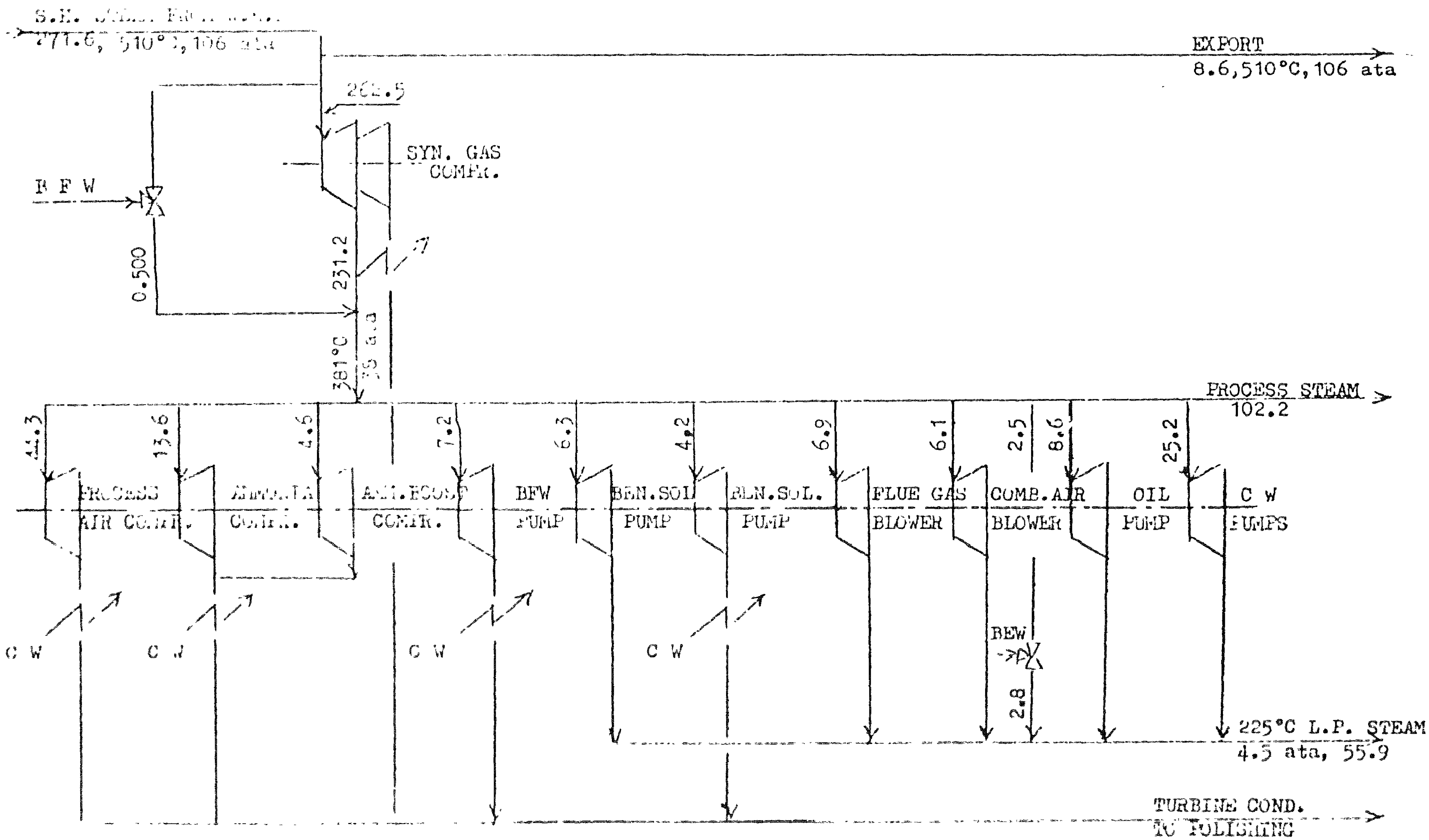


FIGURE - 2. STEAM BALANCE FOR A TYPICAL GAS BASED 1350 T/D AMMONIA PLANT.

FIGURES ARE IN T.P.H.

Plant Management in Fertilizer Plant

Plant Management in Fertilizer Plant

1.0 Introduction

Fertilizer Industries are energy and capital intensive. The fertilizer manufacturing process also involves hazardous conditions and risk to plant, personnel and public. Proper Maintenance Management has been observed as one of the important elements towards overall improvement of the fertilizer industry, specifically in terms of energy and environment effectiveness. It has been observed from performance parameters that maintenance productivity has direct relation to energy consumption and also environment performance. This article describes the latest developments in plant maintenance management that can play stellar role in energy and environment management of Fertilizer Industries.

2.0 Maintenance management strategies

The development in maintenance management has been based on technological advancements from conventional Breakdown Maintenance to Preventive Maintenance, Predictive Maintenance, and Proactive Maintenance Strategies. Different management theories like Reliability Based Maintenance and Total Productive Maintenance (TPM) approach the selection and utilization of these technologies from different perspectives.

Breakdown Maintenance is possibly the weakest strategy as it is bound to increase down time, energy consumption and also may be the root cause of many safety and environmental disasters. Due to these deficiencies, it is possibly the last choice of a maintenance management function, however still practised many a times rather by compulsion due to many limitations. While it may not be possibly to completely eliminate breakdown maintenance, it would be prudent to limit it to applications where the consequence of failure would be negligible for plant availability, energy loss and environment & safety.

Preventive maintenance emphasizes on carrying out periodically scheduled activities on the equipment either to avoid the breakdowns or identify the condition well before it can turn into a breakdown. A simple preventive maintenance activity like regular cleaning of motors can give rise to considerable savings in heat losses and also failure of motor windings. However even preventive maintenance strategy has pitfalls that the material consumption may be more than ideal or the human intervention in the equipment technology may aggravate the failure rates rather than obviate it.

Predictive maintenance using Condition Monitoring Techniques can to a large extent, solve the deficiencies of both breakdown and preventive maintenance strategies. Even indirect preventive maintenance, known as subjective condition monitoring using human senses, would be able to identify failures in advance and aid in taking corrective action. Both simple aids and instrumentation enhance the predictive maintenance capabilities to solve many equipment failures, energy losses, environment and safety problems etc.

Proactive maintenance strategy advances over the predictive maintenance technology in its ability to identify machinery deviation even before it begins to develop. The ability of some monitoring instrumentation to track the hydraulic oil contamination at even the ppm trace levels and eliminate them simultaneously using cleaning equipment simultaneously is an example of proactive maintenance strategy.

3.0 Predictive maintenance & condition monitoring

An examination of the reliability of ball and roller bearings showed that their service lives differed considerably. For the purposes of the test, a number of ball bearings were utilized under identical conditions. After a certain period of time, 10% of the bearings had broken down. However, it took twenty-five times as long for the last bearings to fail. If in the course of preventive maintenance all ball bearings were to be replaced after a period of time when 10% of the bearings tend to fail, the potential lives of the remaining 90% would be wasted. 90% of the bearings would be replaced too soon, and yet there would be cases of unforeseen bearing failure. On the other hand, if the condition of each bearing is established during operation by continuous inspection and replacement is carried out only when it appears justified, we achieve the following advantages.

- Fewer bearing replacements
- Reduced bearing consumption
- Increased operational reliability
- Less need for planned stoppages for bearing replacements

3.1 Condition monitoring with simple aids

It is wrong notion among us that for carrying out objective condition monitoring, we shall always require complicated instruments. Actually there are methods available and methods could be developed to do the same with simple aids. A few examples of using simple aids for condition monitoring without stopping the machine are given below

Example 1: For monitoring the condition of screwed or riveted joints a hammer test can be adopted and inferences can be drawn by listening to the sound, to have a more objective inspection a sealing lacquer can be applied between the head and its support. The slightest movements in the joint will cause the lacquer to crack and this can be detected.

Example 2: Any moving component like open gears, V-belts, and chain drive mechanisms can be inspected visually with the help of 'Stroboscope'. Actually when the frequency of flash light

is matched with the speed of the rotating or moving component, it appears to be stationary to our eyes and the same can then be visually inspected.

Example 3: In a static equipment having wear plate, the extent of wear on the wear plate can be monitored by drilling a small hole from outside to such a depth that a wire can be pushed through the hole when plate is worn to such an extent that it must shortly be replaced

Example 4: In a flexible pin and bush type of coupling, the wear of the rubber bushes can be easily checked by marking the coupling halves. As the coupling is loaded, the marks separate. As the rubber bush wears, dimension 'A' (the distance of separation of the marks) increases. A maximum value of dimension 'A' can be set as a limit when the rubber bushes are to be replaced. Dimension 'A' can inspected when the coupling is running with the help of a stroboscope.

Example 5: By application of another simple aid used by various industries in our country now, known as 'temperature tapes' and 'temperature chalks', the surface temperature of any metal surface can be determined Thus the electrical motors, bearings and gearboxes can be monitored to avoid failures due to overheating.

Example 6: To monitor the condition of lube oil in service a simple aid known as 'Viscosity comparator' can be used. This aid works on the principle that when the oil becomes more viscous due to presence of sludge or when the oil becomes less viscous due to fuel dilution, etc., the fluidity of the used oil will be affected.

Example 7: The water content in lubricating oils and transformer oils can be monitored to decide upon the oil change periods with an aid called 'water test kit'.

Example 8: For monitoring wear or corrosion in static equipments different ultrasonic thickness gauges can be used quite successfully.

All the above examples depict objective inspection techniques with simple aids on running machines/equipment. There are also other aids available for objective inspection but the limitation is to stop the machine. For example some of these aids could be different type of gauges for dimension checking; V-belt tensiometer for checking tension on V-belts and

'boroscopes/endoscopes' for monitoring condition of diesel engine cylinders or heat exchanger tubes, etc. These techniques are also very useful and should be applied whenever there is a planned shutdown of the plant.

3.2 Condition monitoring using modern advanced instruments

In single stream process plants like the modern fertilizer plants, it is also required in addition to use periodic and on -line condition monitoring techniques and systems using sophisticated instrumentation to ensure optimum plant availability and personal safety. Of course, heavy damage to the high speed giant rotating machines can also be prevented by using these techniques. The different techniques and systems used in this category are explained below:

3.2.1 Vibration/Signature Analysis

This is very advanced technique and is very useful for on-line monitoring of high speed rotating machines like turbo machinery, multistage centrifugal compressor, etc. This technique should be used for critical machines only because it is a costly technique and it requires lot of skill to interpret and analyze the readings. The characteristics used to diagnose the incipient failures and also the nature of failures are amplitude (peak to peak displacement, velocity and acceleration) and frequency of vibration. The principle is that as failure develops, the amplitude of vibration increases and depending on nature of failure, a particular frequency of vibration is generated

3.2.2 Shock pulse method (SPM)

This is very useful and economically viable method to monitor operating condition of antifriction bearings. In fact this technique was developed after observing that the diagnosis of operating condition of antifriction bearings with vibration analyser is extremely difficult as the amplitude is unsteady and frequency is very high Shock pulse method is based on the principle that when a surface defect is developed on the rolling element or the races, a mechanical shock will be generated This shock intensity is measured with shock pulse meter in terms of dB to monitor the operating condition of antifriction bearings The interpretation of the results is quite easy and be instrument is very portable

3.2.3 Spectroscopic oil analysis procedure (SOAP)

SOAP is a technique to monitor condition of machines by analysing used oil samples. It is an indirect method. The principle of this technique is that is measures concentration of wear particles of different elements present in the used oil sample with the help of a 'Direct reading spectrometer' The wear debris will be microscopic particles forming a homogeneous colloidal suspension in oil. These particles are too small to be removed by filter. A normal wear rate may

be established for a particular metal in a particular system. Any condition which increases the friction between moving parts will accelerate the wear rate and thus be detected by soap.

3.2.4 Ferrography

Ferrography oil analysis enables a detailed examination to be made of the microscopic particles generated by wearing surfaces and so can yield valuable information about the condition of components. The basic concept involves the magnetic separation of iron & steel (ferritic) wear debris from a lubricant and arranging it, according to particle size, on a glass slide for subsequent examination through a microscope. The particle sizes may range from submicron to several hundred microns. During severe wear, when failure is beginning, the deposit will change drastically the total quantity of debris will increase, there will be a greater proportion of larger sizes, and the maximum size will also increase.

3.2.5 Thermography

This technique is based on measurement of infrared radiation emitted by different materials at different temperatures. The surface of the object to be monitored is scanned with a camera which produces a thermal pattern on a video screen corresponding to the temperature distribution. This helps in locating the hot spots because the intensity of light at each point of the screen depends on temperature at corresponding point on the object. The greatest advantage of thermography instrument is that the hot spots can be detected from a distance without requiring any contact with the object and a big area can be scanned very fast as from maintenance point of view we required to know only the hot spots and not the absolute temperature. Thermography is very useful for monitoring reactors, heat exchangers, storage tanks etc. to identify failed insulation conditions and also electrical transmission and distribution systems like cable boxes, circuit breakers, transformer, contractors, insulators, etc. The insulation strength of high voltage motor windings can also be monitored. It is seen that if a single catastrophic failure can be avoided, the money saved and to personal safety ensured will pay back more than the cost of the instrument.

3.2.6 Acoustic-emissions testing

When vessels or piping systems are hydro-statically tested, stresses in the specimen cause discontinuities to emit high frequency sounds that can be picked up by piezoelectric sensors positioned at the specimen surface before the start of the test. Sound waves received by the sensors are then fed as an electrical signal into an analyzer system that count either the total number of acoustic events occurring in the specimen, or only those in a prescribed area. At their

current level of development, acoustic emission testing systems are capable of indicating over pressurization, and imminent catastrophic failure. The more elaborate, multichannel, computer monitored system can flag problem-areas in large structures and pinpoint the sources of the acoustic emissions. For a truly thorough examination, though, a suspicious area located by acoustic omissions testing should be checked out with more-conventional nondestructive testing techniques, preferably radiographic or ultrasonic.

3.3 *Systematic Application Of Condition Monitoring*

One of the problems of condition monitoring is the state of confusion generated by the wide variety of monitoring techniques. Even within the field of vibration monitoring, there is a profusion of measurement methods each with its particular virtue. Each technique requires a special skill and understanding and some of the more useful techniques have been developed only in the last decade

The key feature of condition monitoring, whatever the technique in use, is the accumulation of data, which at the time of collection seem to have limited value, however, only when sufficient data are collected can normal condition and possible deviations be established and redundant data cease to be accumulated. Thus keeping records is essential to any monitoring programme. To keep paper work to a minimum the data recording system should be devised to provide the important information clearly to the decision maker. Where possible the forms devised for collection of data should also serve to present the information necessary for decision making so that transfer of data is avoided. For example, where the trends in a monitored parameter are used to indicate plant condition it is useful for the data to be plotted directly onto graphs since the mind can absorb visually presented data more effectively than written data. Unfortunately, in the early stages of a monitoring programme there is considerable redundancy in measurements. Only when experience of normal conditions and malfunctions has been obtained will the engineer be able to cut down on the number of measurements made. The importance recording all relevant particulars of the machine and of the monitoring equipment and tests cannot be over emphasized. One of the most common difficulties encountered by the decision maker, when a monitoring technique detects a trend indicative of failure, is lack of data. Where many machines are operated consideration should be given to the advantages of computer data storage and presentation

4.0 Total productive maintenance (TPM)

Technology oriented developments like condition monitoring as described above alone have failed to produce desired results. It was felt that human participation is a vital element in achieving total improvements and hence led to practice of methodologies like TPM. Conceptually, TPM is

departure from the "I Operate - You Fix" approach to "I Operate and I maintain" philosophy. It is implementation of productive maintenance by all employees, based on the principle of involvement of all in improving equipment performance from operators to top management TPM takes on the challenge of Zero losses, meaning zero failures and zero defects. When there are no failures or defects, equipment effectiveness improves, costs are reduced and stock can be reduced and hence productivity improves. In addition to the tangible effects, TPM also has intangible effects that are not represented in figures like positive work culture, improved motivation levels, dynamic and enthusiastic work force improved working conditions, clean & safer environment etc. The goal of TPM is to maximize equipment effectiveness or in other words the pursuit of economic LCC (Life Cycle Cost) of equipment/physical assets. Industries revolve around man - machine system and TPM aims at maximising the effectiveness of this man-machine system at the minimum LCC. In order to maximise the effectiveness, TPM focuses firstly on "Eliminating Big Losses In Equipment " that interfere with the effective operation of the system The Big Losses are:

Down Time Losses	⇒	Failures: Downtime losses due to unexpected breakdowns
	⇒	Set Up & Adjustment Losses
Speed Losses	⇒	Idling & Minor Stoppages
	⇒	Reduced Speed
Defect Losses	⇒	Defects in process
	⇒	Reduced Yield.

Thus, as can be seen above, TPM results in Overall System Effectiveness/Overall Equipment Effectiveness (OEE) through the combination of the availability, performance efficiency and the rate of quality products. Secondly TPM emphasizes on Periodic Maintenance/Preventive Maintenance Through Autonomous Maintenance/Small Group activities.

4.1 *Small group activities in TPM*

Small group activities in TPM are of the company-led type. What gave concrete form to this company led type was the overlapping organization of small groups. In general, small group activities are confined to on-the-floor workers, but in TPM an organization is built that overlaps at several levels of group of executives (TPM Promotion Committee) down to small groups of on-the-floor workers i.e. an overlapping organization of small groups. The aim is to have the leaders at each level fulfill roles of connection by acting as members of the small group of the

level above, thus improving vertical and horizontal communication and unifying the top-down, company-led activities and bottom-up, small group activities.

When small group activities only involve on-the-floor workers (especially activities of independent type), they often become stereo-typed or lack vitality. In the case of TPM, however, all employees from top management down to on-the floor workers participate, each level of the organization is aware of its role and the whole company demonstrates a high level of vitality.

4.2 Autonomous maintenance activities by operators

Autonomous maintenance activities by operators are one of the main features of TPM, and are a key point in its development. Changing the lack of interest in maintenance on the part of operators, who think that "I'm the operator, and you're the maintenance man"' to developing autonomous maintenance - i.e. "autonomously maintaining the equipment one uses by oneself" - is not something that can be done overnight that it takes two to three years from when TPM is first introduced to when the introduction stage is completely implemented. This is because it takes time to change the attitudes of people Under this method, the equipment which one is currently operating is used for on-the-job training, and the operator gradually acquires maintenance knowledge and skills through training and implementation at each step. As he moves up through the steps, he gradually gains a willingness to implement TPM. This consists of the following seven steps

- Initial clean-ups;
- Measures against the causes of dust and dirt and places difficult to clean and lubricate;
- Formulation of cleaning and lubrication standards;
- Overall check-up;
- Autonomous check-up;
- Orderliness and tidiness;
- All-out autonomous management.

With autonomous maintenance activities through this step method, the workers and equipment improve as the steps are completed Splendid results are obtained, including the elimination of the six big losses, improved overall equipment effectiveness and the creation of a pleasant workplace.

4.3 Steps in evolving TPM program

The program for developing TPM is divided into twelve steps, from the preparatory stage through the stages of commencement and implementation right up until it has been firmly established.

Step 1: Announcement by the top management of the decision to introduce TPM The outcome of TPM depends on the top management itself to firmly resolve to introduce TPM and then announcing this intention to all the employees.

Step 2: Education and campaign on the introduction of TPM: Together with carrying out training at each level so that all employees, from the top down to on-the-floor workers, can correctly understand TPM, a campaign through poster slogans and so on is carried out and an atmosphere for commencing TPM, is built up.

Step 3: Creation of organizations to promote TPM Creation of such organizations as a company-wide promotion committee, department promotion committees and special working groups for each theme, and the establishment of a TPM promotion secretariat.

Step 4: Establishment of basic policies and goals of TPM. Survey of the actual situation of overall equipment effectiveness and the six big losses and the establishment of goals and forecast of expected results

Step 5: Formulation of a master plan for evolving TPM. Drawing up a schedule for each of the activities that form the pillars in evolving TPM, from preparations for its introduction up to being assessed. Once these various preparations are completed TPM is "kicked off" - i.e. the commencement of its introduction - in **Step 6**

The stages of introducing and implementing TPM (Steps 7-11) are the "five activities that form the pillar in evolving TPM" that were described earlier "Step 7 · Improvement of the effectiveness of each piece of equipment" and "Step 8 Formation of an autonomous maintenance setup" are commenced immediately after kick-off When autonomous maintenance activities first begin, the maintenance department shall be very bust backing up the operation section According "Step 9 Creation of a planned maintenance set up in the maintenance department" and "Step 10 Training to improve operation and maintenance skills" commence at least six months after kick-off It is effective to commence "Step 11. Creation of a setup for the initial management of equipment" after information has been accumulated on the points of disorder in the reliability and maintainability of equipment currently in operation.

Once TPM is firmly established - i.e. "Step 12 · Perfection in implementation and increased TPM level" - the company continues to challenge ever higher targets.

5.0 Safety and environment improvement

Maintenance management is nowadays inseparably linked with modern safety and environment improvement techniques. Many of the plant and environment accidents of the fertilizer industry have been correlated to improper operation and maintenance of the plant and equipment. Accident investigation reports have pointed out the necessity to involve plant maintenance functionaries in the initial stages of design and procurement of the equipment and also safety enhancement techniques like Risk identification and assessment. Modern risk assessment techniques like HAZOP & HAZAN come in handy for identification and assessment of risk to the man, machine and environment

6.0 Risk analysis

Risk Analysis begins with the identification of the principal hazards which are normally fire, explosion and toxic release and then evaluating the identified risks quantitatively. With the growing complexity of the process plants, more systematic and searching methods for risk identification and quantification have been developed over the years and the latest techniques being HAZOP & HAZAN.

The methodology adopted to carry out the study on "Risk Analysis" basically involves:

- Identification of hazards/risks through HAZOP and/or a "Safety Audit"
- Analysis of the risks identified.
- Quantification of the major risks in terms of their probability of occurrence and their consequences.

7.0 Risk identification

The identification of areas of vulnerability and specific hazards is of fundamental importance in Risk Assessment techniques. The different techniques used for risk identification are:

- Hazard and Operability Study (HAZOP) ⇒ Hazard Indices
- Safety Audits ⇒ Checklists
- Screening for hazardous chemicals ⇒ Feedback from workforce.

Depending on the nature of industries, their processes, chemicals handled, operational conditions etc., one or combinations of the above techniques is used for risk identification.

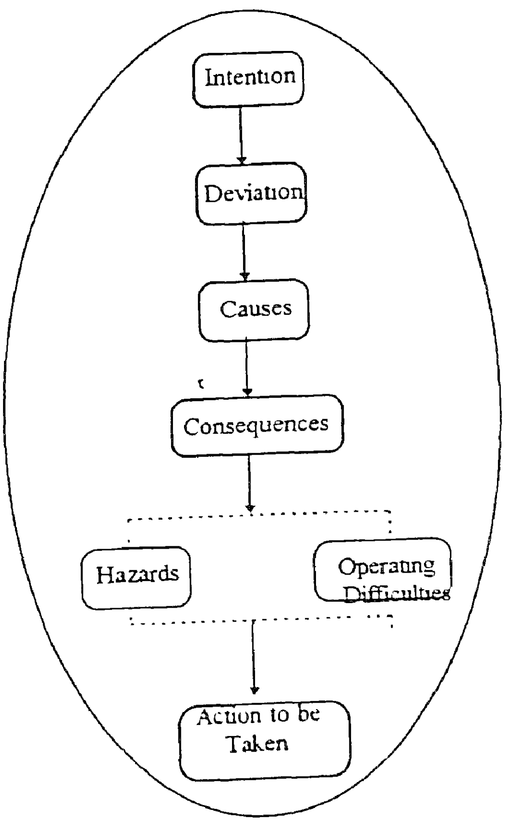
8.0 Hazop study

The latest technique for the hazard identification is the Hazard & Operability study (HAZOP). The basic concept of HAZOP is to take a full description of the process and to question every

part of it to discover what deviations from the intention of the design can occur and what their causes and consequences may be. It is done systematically by applying the following guide words

None	*Part of*
More of	*Reverse*
Less of	*Other than*
As well as	

HAZOP - THE 5 STEPS



9.0 Safety audit

A safety audit examines and assesses the standards of all facets of a particular activity in detail. It extends from complex technical operations and emergency procedures to clearance certificates, job description and housekeeping etc. In general a safety audit has the following five main elements:

- Identification of possible loss producing situations.
- Assessment of potential loss associated with these risks.
- Selection of measures to minimize losses.
- Implementation of these measures within the organization.
- Monitoring of the changes.

10.0 Risk quantification

For an effective hazard control, the impact of the identified risks are to be quantified in terms of fire or explosion effects, toxic dispersion, vapor cloud hazards, flame jet lengths, heat radiation effects and their probability of occurrence. Risk quantification provides a relative measure of the likelihood and severity of various possible hazardous events and enable the emergency plan to focus on the greatest potential risks. As a result of risk quantification the hazards can be ranked as high risk (high probability and severe consequences), moderate risk (high probability and mild consequences or low probability with severe consequences) and low risk (low probability and mild consequences). The following techniques are used for evaluating the hazards.

- Fault Tree Analysis
- Consequence Analysis

11.0 Fault tree analysis

Fault tree analysis is a particular application of formalized deductive logic for system safety and reliability analysis. It visually depicts the inter-relationship of component states or combinations of component states that can result in the occurrence of a specified undesired system state (e.g. total system failure or plant hazard) defined as the top event of the fault tree. Having established this inter-relationship the frequency for the undesired system state can then be predicted by assigning frequencies/probabilities for the existence of each component state or combination of component states capable of leading to the top event and processing the numerical inputs mathematically.

Thus Fault tree is constructed in two stages: First the construction of Fault Tree logic which necessitates thorough knowledge of the system or plant under examination. Secondly determination of the qualitative and quantitative implications of the completed Fault Tree which requires information on the expected frequencies/probabilities of the specified component states or events as already indicated.

12.0 Consequence analysis

Consequence Analysis is carried out to determine the consequences of a potential major accident on the installation, the workers, neighbourhood and the environment. It contains :

- Description of the potential accident e.g. tank rupture, rupture of a pipe, failure of a safety valve, fire etc.
- An estimation of the quantity of material released (toxic, flammable, explosive)
- A calculation of the dispersion of the material released (gas or evaporating liquid)
- An assessment of the harmful effects (toxic, heat, radiation, blast waves etc.)

13.0 Disaster/emergency management

An emergency incident can cause major industrial disasters involving innumerable loss of human lives, plant & property and ecological damage. Hence, it is imperative that the management of emergency is well pre-planned and documented. In its absence, often confusion results and there is precious loss of response time which may result in magnified effects of the incident. The Government of India through its recent legislation has made the preparation of Emergency Plans mandatory for the units involved in manufacturing, storage and processing of hazardous chemicals like the fertilizer industries

14.0 Conclusions

The combination of judicious use of the maintenance strategies, predictive maintenance techniques, human participation in maintenance like TPM and modern safety and environment enhancement techniques have been discussed above as the basis of plant maintenance management. It is envisaged that an integrated approach for the implementation of them would lead to greater performance in availability, energy efficiency, safety and environment improvement in fertilizer industries.

Energy Efficient Process Compressors in Ammonia & Urea Plants

A Maitra
Projects and Development India Limited (PDIL)

Energy Efficient Process Compressors in Ammonia & Urea Plants

1.0 Introduction

Present trend of high capacity single stream Ammonia and Urea Plants require the use of large Centrifugal Compressors. The Compressors used in these applications are critical and non-spared machines. The Compressors play an important role in any modern Fertilizer Plant and rightly considered as the heart of plant The Centrifugal Compressors being the largest rotating machines in the plant are the maximum energy consumers. So reduction of energy consumption of the Compressors significantly improves the overall energy requirement of the plant.

2.0 Brief description of process compressors

2.1 Ammonia plant compressor

The number and type of Process Compressors required for an Ammonia plant will depend on the feed stock used. For the present case, we will limit to our discussions considering Natural Gas as feedstock based on which recent plants have been designed The typical brief specifications of the process compressors for 1350 te/day ammonia plant are given below

2.1.1 Process Air Compressor

Suction Conditions

Pressure (kg/cm^2)	:	Atmospheric
Temperature (°C)	:	Atmospheric

Discharge Conditions:

Pressure (kg/cm^2)abs	:	34
Temperature (°C)	:	168
Flow (Normal/Rated) Nm^3/hr:		56,275/61,900
Power (Normal/Rated) (kw):		10,422/11560
Driver	:	Gas Turbine
Driver Rating (ISO) (kw)	.	19,400

2.1.2 Synthesis Gas Compressor

	Make up	Recycle
Suction Conditions:		
Pressure(kg/cm^2)abs	27	209
Temperature(°C)	38	33
Relative Humidity (%)	100	0
Discharge Conditions:		
Pressure(kg/cm^2abs)	212	225
Temperature(°C)	38	44
Flow (Normal/Rated)Nm3/hr	182,802/ 192,275	645,920/ 678,220
Power (normal/rated)(kW)	23260/24896	
Driver	Steam Turbine	
Driver Rating (kW)	27178	

2.1.3 Ammonia Refrigeration Compressor

Suction conditions	1st	2nd	3rd
Pressure (kg/cm^2)abs	1.05	5.44	7.93
Temperature(°c)	-32	7.5	17
Flow kg/hr	16218	12968	16379
Discharge conditions			
Pressure (kg/cm^2)abs	18.63		
Temperature (°C)	-		
Flow(Normal/Rated)Nm^3/hr	45565 / 50122		
Power (normal/rated) (kW)	4440/4910		
Driver	Steam Turbine		
Driver Rating(kW)	5410		

2.2 *Urea plant compressors*

Although the present trend is for single stream Urea Plant of 2200 tpd capacity. In India it is still in conceptualisation stage. So we are limiting our discussion on 1100 tpd capacity Urea plant which is the capacity for all recently designed urea plants. The capacity of urea plant is considered to be 2x1100 tpd plant considering present generation plants. The brief specifications of CO_2 compressor is given below.

2.2.1 CO_2 Compressor

Suction condition :

Pressure(kg/cm^2)abs : 1.6

Temperature(°C) : 40

Relative Humidity(%) : 100

Discharge Conditions :

Pressure(kg/cm^2)abs : 160

Temperature(°C) : 108

Flow(dry)(Normal/Rated)(Nm3/hr). 20,700/21,500

Estimated Shaft Power(kw) : 5,500

Driver : Steam Turbine

Driver Rating(kW) : 6400

3.0 Measures to reduce energy consumption of the compressor

Mechanical reliability and performance stability required for centrifugal process compressors have been accomplished. However recently there has been a great demand for higher efficiency because of the rising cost of energy. The measures adopted for reduction in energy consumption are described below

3.1 Improved impeller and diffuser design

High efficiency multistage Centrifugal Compressors have been realised as a result of development of high efficiency three dimensional impellers based on the standardisation of fluid dynamics and high performance diffusers.

3.1.1 Impeller design

Fluid dynamic performance mainly depends on the impeller. For a single stage compressor, Head and Flow are defined as

(i) $H \alpha U2^2 = (pi x D x N/60)^2$ (ii) $Q \alpha pi x D x b2 x U2 \alpha D^3(b2/D) x N$

Where H = Head

U2 = Impeller tip speed

D = Outside Dia. of Impeller

N = Rotating Speed

b2 = Outlet width of Impeller

Q = Actual volume flow rate

From (1) it is evident that the impeller tip speed must be increased to obtain a higher head. However the impeller tip speed is limited by the stress of the impeller and the Mach No of relative inlet flow to the impeller blades. So we may assume that impeller tip speed(U2) is fixed by the impeller selection. Again (Dxb2) is fixed for a given flow rate. In general, there is a range of the ratio b2/D where the impeller efficiency shows a higher value. This is because with outlet width increasing beyond certain value, the flow becomes 3 - dimensional and complicated as also with a very small b2, the efficiency reduces due to increase in frictional losses.

Let us now consider, multistage compressors. If impellers which have the same outside diameter are used in all the stages the outlet width of higher pressure stages has to be smaller because of smaller volumetric flows of higher stages. For example in the case where pressure ratio of b2/D with optimum efficiency is chosen for Ist stage, the stage efficiency of higher pressure stages becomes equal to or lower than that of the first stage because of decrement of ratio of b2/D.

Conversely if an optimum efficiency of impeller is adopted for higher pressure stage, the stage efficiency of lower pressure stages becomes equal to or lower than that of higher pressure stage because of increment in the ratio of b2/D. So it is necessary to have impeller blades with 3-dimensional impeller configuration which match the flow in the direction of height of the inlet in order to maintain high efficiency operation obtained by the large ratio of b2/D.The mismatch between the vane orientation and the flow direction is avoided by 3-dimensional blade profile, thereby reducing the incidence losses and improving the efficiency. The performance of the compressor is analysed in computer and supported by model tests carried out by various vendors.

A sample data comparing the polytropic efficiency and polytropic head co-efficient of 3-dimension and 2-dimension impellers are given below

Polytropic efficiency

Mach No	Inlet flow co-eff	2D imp	3D imp.	% Improvement in efficiency of 3D imp.over 2D imp.
0.85	0.08	75%	81.5%	8.6%

Polytropic head co-efficient

Mach No	Inlet flow co-eff	2D imp. Head co-eff.	3D imp. Head co-eff.	% Improvement in Head co-eff of 3D over 2D imp.
0.85	0.08	0.4875	0.566	16 %

From the above, it is clear that because of higher efficiency of 3D impeller the compressor power consumption will be low. The aspect of higher polytropic head combined with higher tip speed result in less number of impellers for a given compression ratio. So the design of the Compressor becomes very compact. The high efficiency 3-dimensional impellers also can handle larger volume of gas than compressors having 2 dimensional blades . This result in decrease in size of the compressor.Also the new designed impeller has been tested for different gases and the new technology is being adopted for manufacturing centrifugal compressor handling different gases.

The manufacturing processes have also been modified to improve the accuracy and quality 3-dimensional impellers are manufactured by using 5-axis NC Milling machine. Also improved welding method using Electron Beam welding and Vacuum Furnace Brazing have been adopted by same vendors to weld the Hub disc with the cover disc to ensure that no weld bead remains in the gas passage This result in impellers of greater reliability, longer life and improved accuracy of performance.

3.1.2 Diffuser design

The outlet width of the impeller increases as a result of adopting high efficiency 3 -dimensional profile and decreasing their outside diameter. So the flow distortion at the diffuser inlet is increased. Moreover as a result of decreasing the size of the impeller and making the tip speed higher,the absolute speed of the fluid becomes more. So the role of diffuser becomes more important The diffusers are meant to convert the kinetic energy of the fluid leaving the impeller into pressure energy. So the higher the fluid speed at impellers outlet ,the greater is the effect of diffuser to total efficiency. Thus the improved diffuser performance helps to achieve higher efficiency of multistage Compressor A stage with vaned diffuser has higher efficiency than one with vaneless diffuser. But vaneless diffuser has a wider stable operating range compared to vaned ones Presently high performance diffuser with ribs or vanes have been designed by various vendors which have higher efficiency and wider stable operating range. The diffuser with ribs are used in stages of higher specific speed to streamline the inlet flow to diffusers whereas vaned diffusers are used for low specific speed cases to get higher efficiency by increasing the flow angle and shortening the path length

The evolution of high efficiency 3 dimensional profile impeller and high performance diffuser along with improved manufacturing method resulted in high efficiency multistage centrifugal compressors. This has made possible in the reduction of shaft power and there by energy saving requirements.

3.2 Use of integrally geared compressor

At the end of forties, the Integrally Geared Centrifugal compressor was developed and initially used for air and later for Nitrogen and other gases. Integrally geared compressor consists of a central bull gear driven by means of helical gearing, a number of pinion shafts on which the impellers are mounted. The thrust forces resulting from the compression process and the gearing are absorbed by thrust bearings of the bull gear and for the pinion shafts by thrust collars.The volute casings are flanged to the gear housing and are equipped with flow directing components like guide vane units and also connections for the suction pipes.

Advantages of Integrally Geared Compressor

The main advantages of Integrally geared compressors are given below

- Impeller inlet flow is axial.
- Impellers in most cases are 3D impellers.
- Impellers have a small tip to hub ratio resulting in ow Mach No. at the intake area with corresponding small flow losses.
- By free selection of stages and by combining various impeller diameters and pinion speeds, the optimum compressor efficiency is achieved resulting in reduced power consumption
- Nearly isothermal compression can be achieved due to recooling before each compressor stage
- Adjustable guide vane units is provided.This ensures optimum control of the machine.
- The compressor is very compact in design. It requires less space.
- Low capital cost.

Integrally geared compressors have already become competitive over single shaft machines because of reduced power consumption, lower investment cost and compactness in design.In Ammonia plant, Process Air compressor of Integral gear type have already been in use. However for high pressure application it had not been used because of limitation of gear design. Multishaft compressors of one to six stages are widely used. In a multishaft compressor, a maximum two impellers per pinion is possible. A six stage compressor has three pinions which can easily be arranged around the driving main bull gear. But with the advancement of gear design, high pressure compressor of Integral gear design is no longer a dream.

M/S GHH Borsig have developed a ten stage integrally geared compressor to be installed in Urea plant of Russia. The machine has already been successfully tested under full load condition at GHH-Borsig shop in march, 1997. The brief specification of the compressor is given below

Fluid Handled	:	CO_2
Flow (NM3/Hr)	:	20,000
Suction pressure (bar)	:	1
Discharge pressure(bar)	:	200
No. of stages	·	10
Speed of last stage(rpm)	:	48,000

The gear ratio from bull gear speed of 1500 to 48,000 is considerable and it could be made possible by 5 pinions. It was not possible to arrange 5 pinions around one bull gear. It was made possible by providing two bull gears. Pinions 1 and 2 with stages 1 to 4 are directly driven by the main wheel. With the conventional multishaft compressor, a third pinion with stages 5 and 6 could be positioned on top of main wheel or at the most a fourth pinion could be put below the main wheel, but a fifth pinion could not be arranged.

So a second main wheel is positioned on the first main wheel The second main wheel drives pinions 3, 4 and 5. The second main wheel has two gears - the first one has a small diameter which is driven by the first main wheel. The second gear has a larger diameter which drives pinions 3, 4 and 5

No intercooling of the gas after 8th stage has been provided as the gas may reach wet area due to cooling. The combination of high rotating speeds and high pressure and density of the gas at the last stages makes surge events dangerous. So additional efforts were made to prevent these stages from surge. The control system was designed to treat the machine as five stages considering each two stages. For each of these stages, suction volumetric flow and polyropic head were determined and compared to individual surge line. The second step was to measure the surge line of each stage with reduced pressure level so that no danger is connected with surge. The measured surge line was then implemented in the control system and used for high pressure operation Apart from this a recycle bypass is provided

With the successful testing of high pressure Integrally geared CO_2 compressor, choice is new available with the plant designers to go in for the same in order to reduce overall power consumption of the plant.

3.3. *Dry gas seals*

The gas sealing system is an important aspect of compressing the gas by Centrifugal Compressors as Compressor efficiency can be improved by reducing the leakage losses. The compressors handling non-hazardous or non toxic gases mostly use labyrinth type seals But for toxic/

hazardous service mostly oil film seals were being used in Fertilizer Plants. But due to the inherent disadvantages of using oil film seals like extensive seal oil supply, drain and gas/oil recovery system, oil leakage, power consumptions for seal oil pumps etc, efforts were on to try new type of seals.

After lot of research, dry gas seal has been developed to overcome the problems faced with oil film seal. In case of dry gas seal, gas is used as the sealing fluid and leakage is maintained very low by limiting clearances between rotating and stationary faces.

A cross-sectional view of a typical gas seal is shown in fig.l The seal is a single unit mounted in a cartridge that slides over the shaft end. The rotating mating ring has shallow grooves etched into the surface facing the primary sealing ring. The grooves have a depth of 100-400 micro-inch. The grooves do not extend all the way to inside diameter of the primary sealing ring so that there is an annular area between primary ring and mating ring. This annular area is called the sealing dam and provides tight sealing at rest. When rotated the spiral grooves pump fluid inwards creating a pressure rise in the grooves. This pressure rise causes the primary sealing ring to lift off against the spring forces creating a narrow gap in the dam area. A typical installation of dry gas seal is shown in fig-2. Small quantity of gas leaks to the low pressure side making controlled leakage. As the depth of the spiral grooves is very narrow, the gas must be filtered before putting in the seal chamber. Tandem seals should be used in case no leakage of toxic gas to atmosphere can be tolerated.

The dry gas seal has got the following advantages.

- Gas leakage loss through the seal is less thereby increasing the efficiency.
- Power loss in seal is about 10% of oil film seals Also no power is required to drive seal oil pump.
- No seal oil and gas separation system resulting in saving in capital cost.

Dry gas seals have already been used in CO_2 compressors in three fertilizer plants in India. For Ammonia Synthesis Gas, there are already reference of 4 installation worldwide. In India the first Synthesis Gas Compressor with dry gas seal is under manufacturing. For Ammonia Compressor also although there are number of references available world wide, but in India Ammonia Compressors with dry gas seals are under manufacturing stage.

3.4 Antisurge controller

Prevention of surge is the most compelling control problem. Surge is a powerful process disturbances that can damage the bearings, seals or even the rotor. Catastrophic surge incidents can result in complete destruction of rotor.

Antisurge control systems have evolved over the years from simple pneumatic minimum flow controllers to analog electronic controllers with special algorithms and numerous computing elements to microprocessor based controllers with special surge control algorithms and the flexibility to handle a wide variety of applications.

When a compressor is operating at less than full capacity ,energy consumption can be minimised by operating close to the surge limit. When a compressor surges, oscillations in pressure and flow will occur and in some cases gas even flows in reverse. The advanced compressor control uses a multi variable input algorithm that can determine how close the compressor is to surge.

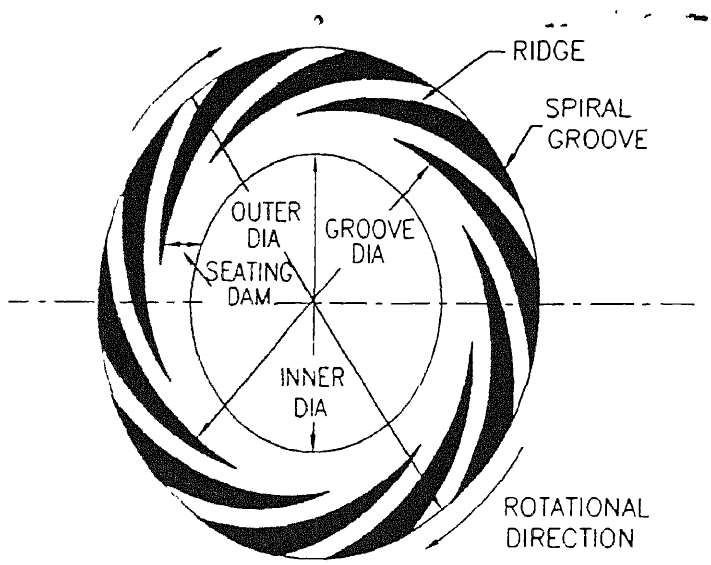
Determination of surge point is not as simple as looking at flow rate and discharge pressure, it also depends on temperature, inlet pressure, molecular weight and other variables. The control system algorithms take these factors into account alongwith measured variables sensed at about 26 times/sec. So calculation of surge point is accurate and fast It is also fast enough to take corrective action such as recycling some gas before surge occurs. Conventional controls can not respond fast enough to the onset of surge and so they are usually operated with a fairly large portion of gas recirculating to avoid surge. The result is energy wasted in recompressing the gas that is recycled.

Presently in some of the compressors installed, series 3 plus Antisurge controller of M/s Compressor Controls Corporation has been installed These controllers employ a unique combination of accurate surge protection and tailored control responses that protect the compressors with smallest possible margin of safety As already mentioned, compressor's surge limit is not fixed with respect to any particular variable ,series 3 plus controller calculates proximity to surge using a multivariable function

4.0 Conclusion

Magnetic bearings is also another option which can reduce the operating cost by elimating oil lubrication required for conventional bearings. Although there are some references of using magnetic bearing in refinery applications, no such reference is available for compressors for fertilizer plant worldwide and so this aspect has not been discussed

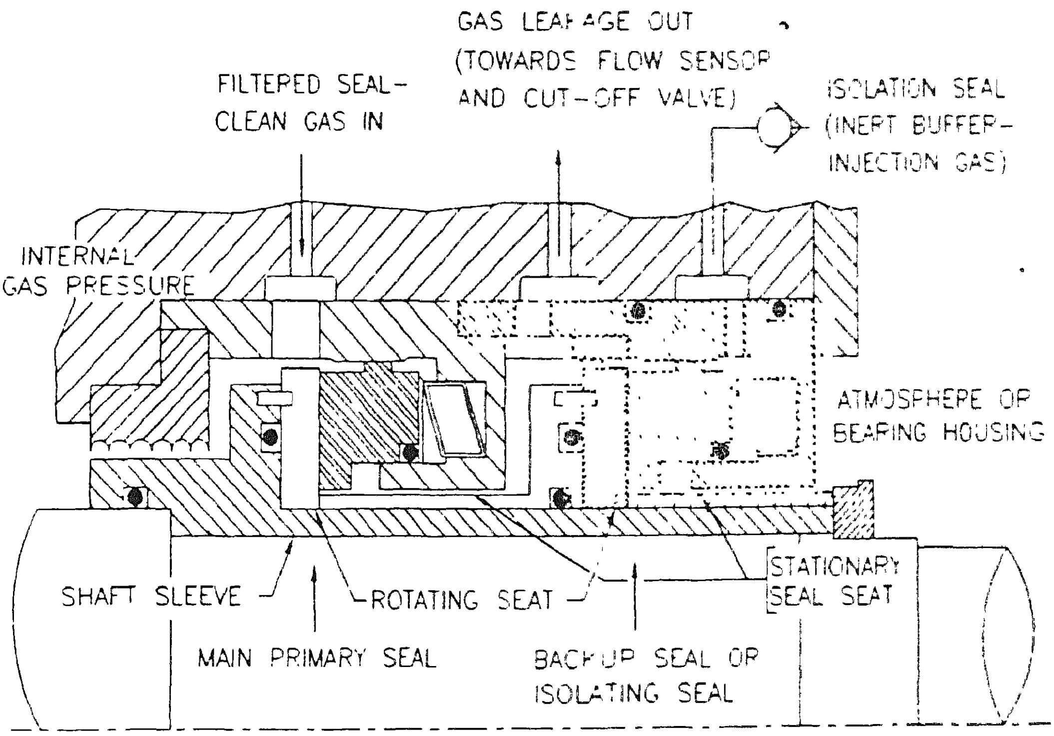
As the energy consumption has become very important in the technology selection of Ammonia and urea processes, great emphasis is laid in laying down the specifications and evaluation of tenders for compressors for Fertilizer Plants so as to select energy efficient machines for the upcoming plants.



SPIRAL GROOVES OF DRY GAS SEAL

FIG. 1

SEAL | DRN BY GHANI M U | DATE 08.01.98 | CKD BY | APPD BY



GAS SEAL SECTIONAL DRG.

FIG. 2

DRN BY GHANI M U | DATE 08-31-98 | CKD BY | APPD BY

SEAL1

Energy Conservation in Ammonia Plant

A K Singh
IFFCO, Aonla

Energy Conservation in Ammonia Plant

1.0 Introduction

Technological innovations are sweeping the world to combat the escalating cost and scarcity of inputs and energy. To survive in this technological milieu it is imperative that we keep ourselves abreast of changing trends. Energy Management, today, is of vital importance to industry in general and fertiliser industry in particular. This article reviews the overall ammonia process with reference to curtailing the losses whatsoever and effectively integrating the overall ammonia manufacturing process with an emphasis on conservation of energy at each step.

Though the technology of ammonia synthesis was developed in the early decade of this century, the large scale production started only after second world war. Subsequently with the demand of nitrogenous fertilizer throughout the world, ammonia production was increased by many folds. The technology was improved and large size single stream plants were developed, thereby reducing fixed and running costs. Increased consumption of energy among fertiliser producers around the world has in recent years put an increasing emphasis on the operating costs of the individual fertiliser plants. As energy costs increase and product prices decline, plant designers continue to design and build ammonia plants with lower and lower energy consumption. Within the ammonia industry this has led to the development of highly energy efficient plants as well as the efforts to improve the productivity and energy efficiency of the already existing plants. The cost of energy per MT ammonia constitutes nearly 95% of the variable cost of production. The high cost of energy and depletion of natural resources is causing concern world over and efforts to conserve energy are being given highest priority. The energy requirement of ammonia plants designed in the beginning of 1960's was approximately 14 to 15 Gcal/MT which improved to the levels of about 13.5 Gcal/MT in mid sixties, 9.2 Gcal/MT in mid seventies, 8.4 Gcal/MT in early eighties and about 7.8 Gcal/MT in late eighties. The energy consumption in the new generation ammonia plants presently has reduced to as low as 6.6 Gcal/MT to 7.4 Gcal/MT depending on the process concept and local site conditions

1.1 Ammonia production

Total ammonia produced in the whole world is approximately 100 million tonnes per year out of which around 10 million tonnes is produced in India. Considering this large production, even a small saving of 0.1 Gcal/MT of ammonia will result an a annual saving of around 1 million tonnes of naphtha for the whole world.

2.0 Energy consumption

The design energy consumption or the expected energy consumption of an ammonia plant when operating at design conditions depends upon a lot of parameters like :

- Feedstock characteristics
- Site conditions
- Process concepts
- Design parameters
- Equipment performance
- Process Control and trip system
- Integration with other units

2.1 Theoretical requirement

The theoretical thermodynamic energy requirement for production of ammonia is approximately 4.47 Gcal/MT for steam methane reforming. However it should be recognised that ammonia cannot be produced at this energy levels as losses will occur in the process of production. Energy losses from the existing designs can be identified by detailed analysis using the first and second law of thermodynamics. Direct first law losses like insulation losses, leakages and vent losses are obvious and can be curtailed by local optimisation. Other losses like pipe line losses and nozzle pressure losses etc. cannot be avoided. Further losses occur in process when catalysts perform inadequately.

The reduction in specific energy consumption over the years has been possible by putting continuous efforts by designers to reduce the heat loss by development of modern technology. In fact much of the cost of a modern ammonia plant is in energy recovery devices such as heat exchangers, waste heat boilers,
condensers, and power recovery equipments. However the reliability factor is not to be sacrificed while going to low energy designs because it is an accepted fact that overall energy consumption of a plant working at higher capacity on sustained basis will always be less.

2.2 Heat loss analysis

A close look at the ammonia plant energy balance diagram indicates that the major sinks for heat wastages are

- Cooling water losses through exchangers including surface condensers
- Furnace stack losses
- Radiation and Insulation Losses
- Miscellaneous Losses

About 91% of the total energy loss is wasted through air coolers, water coolers and surface condensers,around 5% through stack and radiation and about 4% is lost through steam vents, blow down etc. A comparison of thermal losses for IFFCO Aonla Ammonia-I and Ammonia-II plants is given in Table 1.

2.3 Concepts to reduce the losses

2.3.1 Cooling Water Losses

Energy loss through cooling water in the production of ammonia is quite substantial. It is to the tune of 30-40% of the total energy requirement. These losses mainly occur because of process coolers/condensers and surface condensers which function as a heat sink for the condensing turbine.

As is known, the process of ammonia formation is exothermic and lot of waste heat is generated during the process. This heat is best recovered as high pressure steam. However the low grade heat is recovered by preheating DM Water and/or in the reboilers in the purification section. Very low level heat is rejected through the process coolers/condensers.

Ammonia plant generally produces high pressure steam at a pressure of around 105 kg/cm^2g. This steam is let down through a turbine to medium pressure. Medium pressure steam is generally used as process steam or in back pressure turbines which drive various pumps & compressors. Exhaust of back pressure turbines is used. The overall energy recovered from the steam used in process and in back pressure turbines is of the order of around 90%.

However, all the steam produced cannot be used for such process purposes within the ammonia plant. The balance steam is used for driving rotating machineries through condensing turbines, where the utilization of heat energy is only 20-30% as major part of heat (latent heat) of steam is thrown to cooling water.

From the above, it can be seen that if condensing turbines can be eliminated, the inefficient use of energy will be grossly reduced. This is possible if

- A reliable source of external power is available to drive the rotating machineries within ammonia plant and
- (a) The steam generation from waste heat could be reduced to minimum possible, or
  (b) Steam can be exported to other plants in the complex for process purposes though an integrated steam network.
- The generation of steam from waste heat can be reduced by installation of steam superheaters at the outlet of secondary reformer and synthesis converter to superheat the

Table – 1

Energy Input and Losses Comparision at IFFCO Aonla Ammonia–I and Ammonia–II

Energy Inputs

INPUTS	AMMONIA–I Gcal/MT of Ammonia	%	AMMONIA–II Gcal/MT of Ammonia	%
FEED (NG+NAPHTHA)	5 614	71.92	5.56	77.0
FUEL NG	2.255	28.89	3.21	44.46
EXPORT STEAM	–0.088	–1.13	–1.74	–24.09
ELECTRICAL POWER	0 025	0.320	0.19	2.63
TOTAL	7.806	100	7.22	100

Energy losses

Plant Section	Source of losses Gcal/MT of Ammonia: Ammonia–I: Cooling water and Air Cooler	Ammonia–I: Stack and Radiation	Ammonia–I: Misc. vent BDD	Ammonia–I: Total	Ammonia–II: Cooling water	Ammonia–II: Stack and Radiation	Ammonia–II: Misc. vent BDD	Ammonia–II: Total
Desulphurization	–				–			
Reforming	0.500				0.123			
Shift Conversion	–				–			
Condensate Recovery	0 304				0 093			
CO2 removal	0 549				0 336			
Methanation	0 060	0 168	0 108	3.224	0.065	0.278	0.175	2.75
Synthesis & Refrig loop	1 280				1 283			
BFW Turbine	0.079				0.120			
Misc.	0.176				0.283			
Total Gcal/MT	2.948				2.303			
Percentage	91 44	5.21	3.35	100.0	83.56	10.09	6.35	10

HP steam to its required temperature. This will reduce the HP steam generation in the reformed gas waste heat boiler and in the synthesis loop. This apart from the reduction in HP steam generation will also necessitate the elimination of steam superheater coils from the convection section of primary reformer. The heat duty of the convection steam superheater then can be distributed between combustion air preheat and mixed feed preheat. The increase in mixed feed temperature to the primary reformer inlet and combustion air temperatures to the primary reformer burners will result in reduced firing in the radiant section, and hence reduction in stack losses It may be noted that one of the ways of increasing mixed feed temperatures to very high levels is by first preheating the mixed feed to a temperature of about 480-500°C, passing it through a pre-reformer and then reheating the pre-reformer effluents to a temperature of about 600°C.

- If the ammonia plant is situated in a Ammonia-Urea complex, process steam for urea plant and steam for other offsite facilities can be exported from ammonia plant turbine drives after extraction or from exhaust

2.3.2 Furnace stack losses

Stack losses in ammonia plants are to the tune of 2-3% of the total energy requirement. These losses can be reduced by

- Reducing firing in the radiant section,
- Decreasing the stack temperature, and
- Incorporation of better refractory material for insulation

(a) Incorporation of different process concepts and changed process equipment philosophy can result into reduced furnace firing

In processes (like Brown & Root, ICI-AMV etc) using above stoichiometric process air in secondary reformer, the primary reformer exit temperature is be substantially reduced giving rise to reduction in reformer firing. Also, incorporation of process steam superheaters leads to reduction of primary reformer firing as discussed earlier

Steam carbon ratio also plays an important role in the firing in the radiant section of Primary Reformer. To complete the reforming and shift reactions the stoichiometric S/C ratio is 2.1. However, to avoid serious carbon laydown problems in the reforming suction, it is customary to maintain a min S/C ratio of 2.7.1. (The reduction in S/C ratio also reduces the pressure drop in the reforming section).

It may be noted that any reduction in S/C ratio can only be done after incorporation of improved shift catalysts. For a moderately low S/C ratio of about 3:1, a copper doped iron based HT shift catalyst is known to suppress the undesirable Fischer-Tropsch reactions. A further lowering of S/C ratio is possible only by incorporating a copper based MT shift catalyst instead of conventional HT shift catalyst.

Reduction of S/C ratio in the primary reformer also leads to metal dusting corrosion in the waste heat recovery train downstream the secondary reformer. Hence proper care should be taken in selection of material of construction of reformed gas waste heat boiler system.

Reduction in S/C ratio also leads to reduction of heat available in the process gas for regeneration of solution in the carbon dioxide removal system and hence necessitates selection of carbon dioxide removal process suiting to the lower reboiling heat now available from the process gas stream.

(b) The modern day furnaces are designed with an overall efficiency of about 94% and typical stack temperature of 150°C. It may be mentioned that reduction of stack temperature below 150°C may not be advantageous in ammonia plants as process streams are not available to extract this low grade heat. Also the material of construction of the convection section coils becomes a limiting factor because of close approach to the dew point of flue gases

(c) The primary reformer furnaces now a days incorporate better refractory material (ceramic block insulation, soft ceramic blanket insulation, improved fire bricks etc) to have casing wall temperature of around 100-130°C

2.3.3 Radiation/insulation losses

Insulation plays an important role in reducing heat losses. Improved insulation material is now-a-days available to decrease

- Radiation losses from hot equipments/piping and
- To reduce heat ingress to cold equipments/piping

(a) Older plants used unbounded mineral wool/rock wool for insulation of hot parts. However, development in the technology has led to the use of resin bonded mineral wool for hot insulation purposes. Higher densities of resin bonded insulation material is used for high temperature insulation. Better insulation workmanship is also attained in present days by incorporation of preformed pipe sections of resin bonded mineral wool for piping sizes of unto 14" nominal diameters.

However it is said that resin bonded mineral wool is not a very good solution for insulation at very high temperatures (>300°C), as the resin migrates away from the hot surface at higher temperatures. Calcium silicate preformed sections and blocks are a good alternate insulation material at high temperature (because of better mechanical strength with comparable insulating properties),though it offers difficulties in actual application especially at bends in the pipes. A best possible combination for high temperature insulation could be the use of calcium silicate in the first layer to reduce the temperature below 300°C and then use of subsequent layers of resin bonded mineral wool above that.

(b) Older plants used thermocol for cold insulation purposes. Development in technology has led to the use of polyurethene foam blocks preformed sections as preferred materials for cold insulation. Latest trends in cold insulation is to have insitu foaming of polyurethene foam, which eliminates voids in the insulation and hence improves insulation efficiency.

2.3.4 Miscellaneous losses

These include losses because of boiler blow down, process and steam vents, losses through relief valves and losses because of leakages.

Modern day plants incorporate use of vent valves with very high leakage class and high quality relief valves to reduce the leakages and hence give very low level of losses. Also care should be taken to reduce leakages by keeping a high level of maintenance in the plant.

3.0 Process steps and energy saving features in ammonia production

Almost all ammonia plants are designed on the basis of overall process scheme introduced some 30 years ago, featuring the following main sections :

- Hydrogen production
- Syngas purification
- Ammonia Synthesis
- Utility section

The process steps in the hydrogen production section are

- Feed desulphurization
- Primary reforming
- Secondary reforming
- Carbon monoxide shift conversion using high temperature and low temperature shift catalyst

The syngas purification section includes

- Carbon dioxide removal section
- Methanation section

The ammonia synthesis section includes

- Synthesis gas compression and
- Ammonia Synthesis and refrigeration

Utilities include

- Condensate stripping
- Steam system
- DM Water and BFW systems

3.1 Desulphurization

This step uses conventional techniques for desulphurizing natural gas, such as a ZnO bed or a combination of Ni-Mo and/or Co-Mo and ZnO beds (with recycle hydrogen). When Ni-Mo/Co-Mo is required for hydrotreating, hydrogen is provided from the Synthesis Gas Compressor interstate or synloop purge.

3.2 Reforming

The hydrocarbon feed stock is steam reformed in this section in two main steps.

3.2.1 Primary Reformer

The first step of steam reforming is accomplished in the primary reformer which is arranged in the form of a furnace. The reforming reaction is carried out at high pressure over a nickel based catalyst placed inside tubes and the endothermic heat requirement for the reforming is supplied by firing fuel at the outside of tubes. Older plants used a pressure of about 32 kg/cm2g at tube outlet for reforming whereas in modern plants the trend is to use higher pressures owing to the development of superior alloys for reformer tubes. Since the reforming reaction entails an increase in the volume of the gas, significant savings in compression energy are possible by increasing reforming pressure. Another advantage of increasing the reforming pressure is that the higher the pressure, the higher is the grade (temperature) at which the heat of condensation of the surplus steam remaining after shift conversion is recovered

However a serious disadvantage of elevating the reforming pressure is that it exerts an unfavourable mass action effect on the equilibrium. To compensate this an increase in heating duty is necessary

Another important operating parameter for the reformer is steam to carbon (S/C) ratio. Older designs used S/C ratio of 3.5-4.0. A high S/C ratio of this range has three main advantages namely it prevents carbon deposition on the catalyst, provides the extra steam necessary for the shift conversion of carbon monoxide and reduces the risk of carburization damage to the tube material.

However owing to the development of superior catalysts the recent trend is to use lower S/C ratios which reduces the total mass of gas to be heated and hence the fuel firing. Lower S/C ratios also result in low pressure drop in the front end of the ammonia plant resulting in considerable energy savings. As discussed earlier, the S/C ratio in a modern low energy plant is varied between 2.7 to 3.0.

The important components of the primary reformer are the following :

- Reforming Catalysts

  The criteria of a good primary reforming catalyst are

  - It should achieve the desired conversion of the hydrocarbon feed at lowest possible tube wall temperature and pressure drop without forming carbon.
  - It should have a reasonably high life time, atleast matching turn-around intervals.
  - It should withstand severe conditions faced during start-up and shut-downs.
  - It should be able to withstand insiteu regeneration after accidental poisioning or carbon deposition.

The above criteria can be fulfilled by all the leading catalyst producers in present days. The main factors affecting the catalyst activity are chemical composition, surface area and manufacturing process. Also the heat transfer characteristics which are governed by the size and shape are of the equal importance for the performance of the catalyst.

The active component of the primary reformer catalyst is metallic nickel which is finely dispersed over the support material as crystallites produced by reduction of nickel oxide. The support material nowadays are α alumina, calcium aluminate and magnesia α alumina spinel. α alumina is the predominant support used in North America and is becoming popular in other parts of world also. Calcium aluminate is still widely used, specially in naphtha reforming, on account of its natural alkalinity which helps to suppress carbon deposition. Magnesium aluminate support gives a larger specific surface area but it must be calcined to a higher temperature to ensure it contains no free magnesium oxide, which would hydrate at temperatures below 300°C.

As mentioned earlier, the size and shape of catalyst influences the performance greatly. Since the main mechanism of heat transfer from the inner tube wall to gas is convection, its efficiency depends on how well the gas is distributed in the catalyst bed and hence on the geometry of the catalyst. A better geometrical shape coupled with high activity gives a lowering in the tube skin temperature. Due to this, the catalyst producers are coming up with shape optimised catalysts with good packing characteristics to achieve better performance.

- Reformer tubes

  Older plants used HK-40 or equivalent alloys as material for reformer tubes. However the development of manurite 36XM or equivalent alloys having niobium stabilization and high nickel content was a major breakthrough in high temperature materials. Recent development in these alloys has led to the advent of even better materials (manurite 36 XM or equivalent) additionally incorporating titanium and lanthanum having substantially higher stability. On account of the superior high temperature strength and stability of these materials, it is now possible to design reformers with outlet pressures as high as 43 kg/cm^{2}g. These materials also offer good revamp alternative for old reformers as enhanced quantity of catalyst can be loaded in the thinner tubes after retubing and hence throughput can be increased

- Furnace design

  Mainly two type of furnaces are used for reformers namely top fired and side fired. The flow of process gases and flue gases is co-corrent in top fired furnaces which permits high heat flux design. These furnaces are preferred for large capacities. Since the firing occurs only at one level, the number of burners is less in these. However the adjustment of heat input is possible only to a limited degree. The radiation efficiency in top fired furnaces is higher. The side fired furnaces accommodate burners at different levels in the side wall and hence permit very uniform heat distribution which may additionally be adjusted by control of individual burner firing. However since only one or two rows of tubes can be incorporated in a radiant chamber, this puts a limitation on capacity which can then be increased by incorporating multiple chamber design only. The modern day furnaces incorporate improved burner design giving better performance and less NOx emission because of growing public concern.

3.2.2 Secondary Reformer

After primary reformer, the gases flow to secondary reformer where air is introduced to supply nitrogen for the synthesis of ammonia. The air to secondary reformer maybe introduced in stoichiometric requirement. However few process routes opt for excess process air. The secondary

reformer is a refractory lined reactor where the temperature of the gases increases because of combustion and then reforming is carried at elevated temperatures. Secondary reformer incorporates catalyst with lower nickel content and lower activity because of high temperature operation. Old day secondary reformer catalysts were tablet shaped or rasching rings. However catalyst manufacturers are now preferring shape optimised catalysts for this service also.

3.3.3 Pre-reforming

Modern day plants based on NG/naphtha feed stock also incorporate the use of pre-reformer at upstream of primary reformer. Incorporation of pre-reformer facilitates more stable operating conditions to the primary reformer and can also provide flexibility to reduce S/C ratio. Special design concept like reheating pre-reformed gases to high temperature before flowing to primary reformer tubes can also be developed to reduce primary reformer firing and size.

- Shift-Conversion

  After recovery of waste heat the secondary reformer effluent gases flow to a typical two stage shift conversion section. The conversion of carbon monoxide to carbon dioxide with steam is a very important step in the process sequence. A high conversion in this stage is important for high process efficiency as any residual carbon monoxide reduces ammonia production by consuming hydrogen in the methanation step and indirectly it also leads to hydrogen losses in the purge from synthesis loop. A surplus of steam in this stage helps the equilibrium conversion of carbon monoxide but the recent trend is to use lower S/C ratio in reforming for obvious energy efficiency. However reducing the surplus steam lowers the S/C ratio in HTS to a point where the atomosphere is highly reducing. This reduces the Fe_30_4 in the classical HTS catalyst not only to FeO but at last partically to metallic iron It also leads to Boudouard reaction occurring significantly leading to accumulation of carbon in the catalyst particles ultimately breaking them to increase pressure drop. In the absence of steam, carbon monoxide also reacts with magnetite to form iron carbide according to reaction

  $$5Fe_30_4 + 32\ CO = 3\ Fe_5C_2 + 26\ CO_2$$

  This carbide is a very effective catalyst for Fischer - Tropsch reaction in which methane and higher hydrocarbons are formed.

  $$(2x + 1)\ H_2 + xCO = C_x\ H_{2x} + xH_2O$$

However, development in the shift catalysts has led to the advent of a copper doped HTS catalyst which suppresses the undesirable Fischer-Tropsch reactions and permits operation with S/C ratio unto 2.9 to 3.0 in reforming section. With even lower steam to carbon ratios an iron free copper based medium temperature shift catalyst is used which operates at 280°C to 300°C. After HT/MT shift conversion step, the gases are passed to a low temperature shift converter containing a copper zinc catalyst where the carbon monoxide content of the gas is reduced to 0.1% to 2%. The LTS catalyst is very sensitive to poisoning by sulphur and chloride and also to high temperatures. However, intensive research and development has produced better LTS catalysts with improved activity, higher resistance to poisoning, low by-product formation and a longer lifetime.

Carbon dioxide Removal Section

The majority of carbon contained in the hydrocarbon feedstock has by now been converted into CO_2 which is removed from the process gas in the carbon dioxide removal section as it is undesirable for the synthesis catalyst. This CO_2 is used in the manufacture of urea in a Urea complex. Considerable progress has been made in recent years in improving older processes/developing new processes which has resulted in the emergence of latest low energy concepts. The first generation single train ammonia plants used scrubbing with an aqueous solution of MEA which consumed considerable energy and also caused problems as the laden MEA solution was very corrosive. However with introduction of Amine Guard-I to IV these problems were solved to some extent. Other CO_2 removal processes used over the years and in the present generation plants are Benfield Process, Benfield Low-Heat Process, Benfield Pressure Swing Process, Giammarco-Vetrocoke Processes with single and double activations. Activated MDEA process from M/S BASF, Selexol Process from UOP etc. The solution regeneration energy requirement over the years has reduced from 2100 Kcal/NM^3 of CO_2 to 300 Kcal/NM^3 of CO_2 in present days. A comparison of various process is given in Table-2 below

Table 2. Salient features of CO_2 removal process

Item Description	Benfiend Process	G V Process	Activated MDEA Process	Selexol Process
CO_2 Purity,% Vol	98.5	99.4	99.8	98.5
CO_2 Slip in product gas, ppm	500	300	50	500
Energy requirement Kcal/NM^3 of CO_2	670-850	620-730	450	300 (approx.)

Selection of carbon dioxide removal process in an ammonia plant depends on considerations like required purity and recovery of carbon dioxide, amount and grade of heat available in process gas for solution regeneration depending in operation of reforming section etc.

Methanation

The gas from the overhead of CO_2 absorber is first preheated and then flows to the methanator where the remaining carbon oxides combine with hydrogen over a nickel catalyst to form methane and water as carbon oxides are poison for the synthesis catalyst. Residual carbon oxides in the methanator effluent gases are less than 10 ppmV.

Ammonia Synthesis

The Synthesis gas after methanation is cooled and then compressed to the required synthesis loop pressure. The Brown & Root process uses a drier and cryogenic purifier ahead of synthesis gas compressor whereas few others use synthesis gas drying in the interstate of compression After compression, the synthesis gas is fed to the synthesis loop where ammonia is produced in the synthesis converter. Depending on the process licencer, different configurations of synthesis converters are used. The waste heat in the converter effluent gases is recovered in a series of exchangers and then the gas is cooled and refrigerated in chillers for product separation.

The inert gases (CH4 and Ar) entering the synthesis loop alongwith fresh make-up gas tend to accumulate in the loop and are purged to maintain optimal pressure levels in the loop. Many plants install a purge gas recovery unit as an energy saving means to recover hydrogen from the loop purge which is circulated back for ammonia production. The ammonia synthesis converter and synthesis catalyst are key items in reducing the energy consumption and/or to increase the capacity. Different designs like axial flow quench converter, radial flow converter with or without interbed cooling, axial-redial flow converter etc. have been used by process licenceers

Old ammonia plants used axial flow quench converters incorporating 3 or 4 beds However these converters presented high pressure drop because of axial flow and low conversion per pass because of reduction in the convertration of ammonia after each bed due to addition of fresh gas through quench. This low conversion per pass demands for high circulation rates which coupled with high pressure drop increases the net energy consumption of synthesis gas compressor. Due to the above disadvantages, radial flow converter are preferred in the present low energy ammonia plants. M/s Haldor Topsoe of Denmark are one of the major designers of radial flow converters worldwide.

Different type of converter designs and loop configuration are supplied. The S-100 converter of M/s Topsoe was supplied first in 1966. However, presently S-200, S-250 and S-300 converter design with standard loop configuration are being offered by M/s Haldor Topsoe. Majority of the loops have been designed with S-200 convertor whereas recent development of S-250 and S-300 design give high conversion per pass and low energy consumption. The table 3 below gives typical comparison of two different loop configurations

Table 3. Comparison of Loop Configurations

Convertor type	S-200	S-300
Operating pressure, kg/cm²g	140	140
Ammonia concentration, in/out	4.2/17.1	4.2/20.7
Relative converter feed flow	1.0	0.75
Relative catalyst volume	1.0	1.7
% of heat recovered for boiling	62	50
Relative compressor power, kwh/MT NH3	B	-29.1
Relative recovered heat, kcal/MT NH3	A	+31,000
Net energy saving, Gcal/MT NH3	S	0.11
Cost difference, Million US$ 1000 MTPD NH3	E	+0.1-0.2

The radial flow converters are characterised by

* Small catalyst particles
* Low pressure drop
* High catalyst activity and
* Ease of operation

Since the gas in a radial converter passes only a thin layer of catalyst the pressure drop is small. This permits use of small catalyst size (1.5-3 mm). Unto 40% more catalytic activity can be installed in the same reactor volume compared to cases where larger catalyst particles are used.

- Influence of design parameters Synthesis Pressure

Synthesis loop operates at very wide pressure range depending upon various specific conditions. Synthesis loops operating at a pressure of about 140 kg cm^2g show a very flat optimum. However, a good criteria for this is that the heat recovered can be utilised in the high pressure steam system and also a reasonable size of main equipment in the loop is obtained.

- Ammonia Concentration

Ammonia concentration at the inlet and along the catalyst bed plays an important role in the calculation of catalyst volume required and operation of synthesis converter. When in operation, efforts are made to keep ammonia concentration at the inlet of a given converter at minimum.

- Partial Pressure of Reactants

Partial pressure of hydrogen and nitrogen affects the reaction rate. They also have considerable influence on the selection of proper material for the synthesis reactor and exit piping as proper precautions have to be taken in order to avoid hydrogen attack and nitrating at high temperature.

- Inert Concentration

Inert concentration plays an important role in energy consumption as it has direct bearing on loop pressure and conversion per pass.

- Refrigeration and Product Separation

A refrigeration compressor supplies the chilling requirement of the ammonia process for the ammonia product. The compressor is either a single case or two case centrifugal machine depending on the refrigeration duty required The energy requirement of refrigeration compressor depends on the configuration and layout of the synthesis loop.

- Ammonia Recovery

The ammonia in the purge gases and flash and let-down gases is recovered in an ammonia recovery unit by scrubbing with water. After ammonia recovery, the gases are sent as fuel to the primary reformer burners. Plants incorporating a Purge Gas Recovery Unit employ a high pressures ammonia recovery for the HP purge gases.

- Condensate Stripping

  The process condensate separated in the front end of the ammonia plant from process gases and the condensate separated from the CO_2 stream are sent to a condensate stripper where the dissolved gases are stripped off. The stripped condensate is returned to the ammonia plant as boiler feed water after it has been passed through a condensate polishing unit. In older plants, condensate stripping was accomplished at low pressures. However in latest plants, it is customary to employ a medium pressure condensate stripper for energy efficiency which uses medium pressure steam for stripping purposes and overheads are used as part of process steam.

- Steam System

  The generation of steam in ammonia plant is by recovering the high level waste heat from the reforming section, the shift conversion section and the synthesis loop. The steam is superheated in the reforming section and in the convection section of primary reformer. The steam is generally produced at high pressure (105 kg/cm²g) and high temperature (450°C - 525°C). However, the steam net work of ammonia plant generally incorporates three pressure levels typically HP at 105 kg/cm²g, MP at 38 kg/cm²g and LP at 3.5 kg/cm²g. The modern philosophy for low energy ammonia plants for waste heat recovery by steam generation is to produce just the amount which matches with the steam requirement of the process and the major drives and ensuring thereby the most efficient recovery of the available heat.

  It is usually found that the energy efficiency is the maximum if high pressure superheated steam is produced. It is seen that the energy consumption for the same process concept increases by 0.4 Gcal/Te ammonia or by more then 5% when the steam system is changed from high pressure to medium pressure level. The discussion of the steam system for any ammonia plant may be done with respect to following two cases.

A) Stand-alone ammonia plant with dedicated utility installations comprising unit which does not import/export steam to/from other installations.

B) A ammonia urea complex in which the ammonia plant can be designed for steam export.

A) For the first case, the net energy consumption of the ammonia plant can be reduced by reducing the steam generation to as low as 3 tons per ton of ammonia produced. In this case following two out of many possible features are discussed.

<u>Installation of Process Steam Superheater:</u>

Installation of process superheaters in the reforming and the synthesis section utilizes the concept of high grade heat recycle partly by superheating thereby reducing the heat

available for steam productions. This superheating of steam leads to elimination of superheater coils in the convection section of primary reformer and gives energy advantage as discussed earlier in this paper.

Use of Gas Heated Reformer:

The use of gas heated reformer (GHR) is gaining increasing importance for high temperature heat recycle. This concept utilises waste heat from the secondary reformer outlet gases for supplying the reforming heat to the mixed feed in tubular heat exchanger type of reformer with catalyst filled tubes. The GHR by heat exchange reforming fundamentally changes the waste heat balance of the process. Most of the high temperature heat is returned to the process and is therefore, not be available for steam generation. The shell and tube design of the GHR, featuring convective heat transfer, results in an optimal heat flux distribution. This gives a very reliable and compact piece of equipment. The major advantages of this concept are

* Reduction in reformer size and reduction in gaseous emission and Nox levels
* High feed gas utilization
* Lower capital costs

However, it may be noted that high capacity single stream ammonia plants cannot be designed with GHR because of mechanical design constraints

B) For an ammonia urea complex where steam export possibilities can be effectively explored, the use of external firing inside the ammonia plant battery limits can be envisaged. This is usually accomplished by using a gas turbine as driver for one of the large compressors, usually the process air compressor. The extra firing in the GT increases the steam production rate by means of a heat recovery unit to a level in excess of the plant's own requirement. This extra steam generated is exported to urea plant in a urea complex. As a typical case study the steam system for Ammonia-I and Ammonia-II plants at IFFCO, Aonla are compared in Table-4 below

Ammonia-I plant steam system

The steam system in ammonia-I operates at three different levels :

* HP steam at 105 kg/cm^{2}g and 525°C
* MP steam at 38 kg/cm^{2}g and 381°C
* LP steam at 3.5 kg/cm^2 and 225°C

HP steam is produced by utilizing the high level waste heat in the reforming section, the shift conversion section and synthesis section.

Ammonia-II plant steam system

The ammonia-II steam system differs from Ammonia-I steam system due to incorporation of a gas turbine in the ammonia plant which serves as a driver for the process air compressor. The ammonia-II plant is designed to export steam requirement of the urea plant. which is generated by recovering the waste heat from the gas turbine exhaust gases.

High Pressure Steam (MT/hr)

Description	Ammonia-I	Ammonia-II
SH Generation		
•From Front End Boilers	213.4	166.2
•From Syn loop boiler	58.3	62.8
•From HRU (of Gas Turbine)		106.0
Total	271.7	335.0
SH Consumption		
•In Synthesis Gas Turbine	231.2	197.6
•Extraction condensing	31.9	36.0
Total	263.1	233.6
•SH Export	8.1	100.2
•HP MP let down	0.5	1.2
Grand Total	271.7	335.0

- DM Water and BFW System

The ammonia plant also incorporates DM water system and boiler feed water system to cater to the need of steam generating boilers.

Medium and Low Pressure Steam (MT/HR)

S N	Description	AMMONIA-I MP STEAM GEN	AMMONIA-I MP STEAM CONSPN	AMMONIA-I LP STEAM GEN	AMMONIA-I LP STEAM CONSPN	AMMONIA-I COND	AMMONIA-II MP STEAM GEN	AMMONIA-II MP STEAM CONSPN	AMMONIA-II LP STEAM GEN.	AMMONIA-II LP STEAM CONSPN	AMMONIA-II COND
1	Extraction	231 2					197 6				
2	HP to MP let down	0 5					1 2				
3	Cond from Syn Turbine					31 9					36 0
4	Ref Comp Turb		13 67			13 67		13 48			13 48
5	Process Air Comp Turbine		44 28			44 25		–			
6	Amm Booster Comp Turbine		4 57			4 57		–			
7	HP BFW Pump Turbine		7 19			7 19		11 69			11 69
8	Benfield Pump Turbine		4 2			4 2					
9	G V Semilean Pump Turbine							5 17			5 17
10	Benfield Booster Pump Turbine		6 34	6 34				–			
11	Lean Pump Turbine							1 84			1 84
12	ID Fan Turbine		6 83	6 83				6 20	6 20		
13	FD Fan Turbine		6 14	6 14				7 39	7 39		
14	CW Pump Turbines		25 24	25 24				9 91			9 91
15	MP Steam to Naphtha Evaporator		–					5 64			
16	Process Steam		101 43					108 89			
17	MP Steam to Urea		–					20 0			–
18	Auxilliaries		9 31	9 31				8 59	8 59		
19	LP Quench			2 92							
20	MP TO LP Letdown		2 50	2 82							
21	LP Steam to Deaerator									4 74	
22	LP Steam to GV Benfield System				31 30						
23	LP Steam to Ref Turbine Induction									8 68	
24	LP Steam to PC Stripper deaerator				28 30						
	Total	231 7	231 7	59 60	59 60	105 78	198 8	198 8	22 18	22 18	78 09

4.0 Instrumentation

Modern day ammonia plants employ extensive instrumentation for point-to-point feed back of the process to the operator and better control. It is mandatory for high reliability for better energy efficiency that the operating personnel be provided with maximum possible information regarding operating conditions of the process, equipments and catalysts. Present day distributed control systems, (DCS), act as a versatile tool in attaining the above by providing all the information to operators in low time cycles and permitting control of the process in a narrow band. However, care should be taken regarding operator friendliness and good operator interface while selecting a distributed control system. The DCS should also have very high on line availability through redundency.

All the ammonia plants also employ an emergency shut down system (ESDS) for safe and reliable operation of the plant. The ESDS ensures safe shut down of the plant as a whole or in sections in the event of emergency situations when process parameters cross safe limits. The system also ensures start up of systems and stand-by equipmetns for the safety of the process. Present day shut down systems generally employ fail safe redundent PLC's.

5.0 Consideration for energy efficiency in operation of ammonia plants

High energy efficiency resulting in low energy consumption is attained with the following :

- Onstream Reliability
- High capacity utilisation
- Continuous long run
- Efficient reformer operation
- Operation of catalysts at most optimum conditions
- Quick start-up to have minimum venting
- Use of interconnection between two ammonia plants (if present in a complex)
- Reduction in shut-down time to reduce vent losses
- Good house keeping
- Energy concious operating personnel
- Evaluation of process and plant
- Improved maintenance
- Short duration scheduled turn arounds
- Use of process optimiser

5.1 Onstream reliability

It may be noted that high on stream factor is very important in attaining high average energy efficiency. Following consideration should be kept in mind in attaining the above right from the project stage.

- Reliable and proven design.
- Adoption of proven process with high operating factor.
- Process with an inbuilt capacity.
- Minimise process steps to the extent possible.
- Choice of reliable equipment.
- Choice of proven vendors for supply of equipments.
- Ensuring high quality of workmanship in manufacture of equipments by following proper codes, standards and inspection procedures.
- Choice of rugged and highly active catalysts.
- Use of milder operating conditions
- Adoption of simple and quick start-up and safe shut down procedures

5.2 High capacity utilisation

If the on stream factor of a plant is high and the plant operates at high load, the average specific energy consumption becomes lower. This is because the continuous operation of plant without interruption leads to minimum vent losses and have lower energy consumption.

5.3 Continuous long run

It is a universally accepted fact that continuous long run of ammonia plants reduces overall energy consumption. A positive step in the direction has been gained in few states in India by getting exemption from statuary inspection of waste heat boilers every year This has led to scheduled turn-arounds to be planned every two year. Similarly availability of improved catalyst also permits change out of catalysts to match to these turnarounds.

5.4 Efficient Reformer Operation

Care should be taken to operate the reforming furnace at design steam carbon ratio and excess air as it is the biggest single sink for energy. Regular checks of the radiant section of furnace is necessary to adjust individual burners Efforts should also be made to maintain the stack temperature at lowest possible safe values

5.5 Operation of catalysts at optimum conditions

All the catalysts in ammonia plant should be operated at safe and optimum conditions to derive best life and energy efficiency. Following are typical operating conditions :

- HDS reactor should best operate at maximum allowable inlet temperature to extract maximum heat from flue gases in the convection section of furnace. However care should be taken to avoid reverse shift reaction by varying the quantity of recycle gas and temperature, if the hydrocarbon feed stock contains carbon dioxide.
- Primary reformer should be operated at minimum possible outlet temperature. However the methane concentration outlet secondary reformer should be watched to have optimum purge from synthesis loop.
- HTS and LTS convertors should be operated at lowest possible inlet temperatures keeping in view their activity and exit CO slip.
- Synthesis convertor and loop should be operated at near design H2/H2 ratio and bed temperatures to attain better energy efficiency.

5.6 Fast Start-up

The ammonia plant start-up should be done in fastest possible time to reduce the venting of the gases and hence energy. This can be accomplished by

- Heating the different catalysts with high but safe temperature increase rates.
- Keeping LTS reactor heated in advance to be inserted in line without delay.
- Keeping CO_2 removal section ready to receive gas.
- Keeping synthesis gas compressor ready for a quick start.If the compressor vendor permits, the machine can be started in advance on inert gas.
- Starting the refrigeration loop in advance.

Present day modern ammonia plants permit a typical cold start-up time of about 20 hours from feed cut in to ammonia production. However the start-up time can be reduced to about 12 to 14 hours in complexes incorporating two ammonia plants by efficient use of interconnections. Ammonia plants generally do not envisage nitrogen heating of methanation catalyst. However incorporation of this can reduce every cold start-up time by 4 to 6 hours

5.7 Use of Interconnection

Energy efficiency can be increased in complexes incorporating more than one ammonia plant by providing and using interconnections in most efficient manner. A typical synthesis gas compressor suction interconnection facilities start-up of one ammonia plant back-end with imported gas from the other unit to reduce the start-up time. The same interconnection can be used to reduce vent losses by exporting synthesis gas to other unit in case of unscheduled shut down of the back-end of one unit.

5.8 Reduction in Shut-down time

Scheduled shut-down time of ammonia plant should be reduced to minimum possible to save energy by reducing venting of process gas. This can be achieved by following a quick, coordinated section wise shut down sequence. If opening of equipments for maintenance is not required in different sections, unnecessary cooling down of catalysts should be avoided in a shut down sequence. Similarly regeneration of the carbon dioxide absorbing solution to a very low degree should be avoided using process gas.

5.9 Good House Keeping

This involves minimising of process and steam vents by close watch, on line repair of leakages, replacement of leaking valves etc. at the earliest when on line repair is not possible, proper attention to steam traps, process drains, regular inspection and repair of insulation etc.

5.10 Energy Conscious Operating Personnel

Without energy concious operating team, the goal of high energy efficiency cannot be achieved. Operating personnel should watch the following continuously :

- Excess air in the furnace
- Stack temperature
- Purge rate
- Process gas leaks through vent valves
- Steam leaks
- Operation of process at optimal conditions

5.11 Evaluation of Process and Plant

Technical department personnel should periodically access the following

- Performance evaluation of rotating machines to decide preventive overhauls.
- Evaluation of static equipments, furnace etc. to asses heat loss.
- Steam balance

5.12 Improved Maintenance

Continuous watch should be kept with the help of routine inspection NDT of static equipments and rotating machinaries to facilitate running maintenance. This reduces unscheduled stoppages of the plant avoiding undue emergencies. Insulation surface temperature survey also helps in maintaining the heat loss under control.

5.13 Short duration scheduled turn - arounds

Scheduled turn-arounds should be planned well in advance by making a consolidated job list. This facilitates arrangements of material and men at proper time. Also hand over procedures for each job should be made and care should be taken to reduce the shut-down time as much as possible by following a tight schedule. Proper inert gas planning for purging/hand over of different section of ammonia plant should be done in advance.

4.14 Ammonia Plant Optimiser

Inspite of energy consious operating personnel keeping continuous vigil on the plant operation, these are some typical constraints that cannot be handled by plant operators continuously in most optimum way. Some of these are

5.14.1 Operation of plant at optimal point

To attain high energy efficiency, the plant needs to be operated at the most efficient point within a narrow band. Keeping numeorous operating parameters, which are interdependent, at the most efficient point within a narrow band is not possible by operator interface.

5.14.2 Feed stock variation

With variation in feed stock steam to reformer, reforming temperature, synthesis loop purge and inert levels should be changed.

5.14.3 Ambient temperature variation

Depending upon the season and also day and night theambient temperature changes. This calls for changes in the speed of compressors and also change in the fuel to furnace to keep the plant at optimum energy consumption.

5.14.4 Equipment limitation

In some plants, certain equipments limit capacity Optimum operation has to be done taking these constraints into consideration.

5.14.5 Capacity variation

Reduced load operation, start up of plant etc calls for a different set of optimum operating conditions

5.14.6 Catalyst activity

Though a slow changing parameter with respect to time, when catalyst age, they call for a different set of optimum operating conditions as regards temperature, pressure, composition etc.

Keeping the above in view, use of optimisers in ammonia plants can be emphasised for better energy efficiency and increase in throughput. An optimiser helps to achieve these goals in steps:

Data Collector

The first step is to collect maximum information regarding the plant and make it available to the operator. In modern day plants, this is already achieved with the use of DCS for process control. Availability of operating parameters in accurate digital display to operators increases their awareness. This alongwith low cycle time of DCS leads to better control of process which is first step in optimisation.

Simulator

A compute is deployed to run the actual plant simulated mathemetical model at design conditions.

Optimiser

This determines the most profitable operating point by superimposing the actual plant operating data on to the simulated plant model and evaluating the deviation from the optimum points. Few commercially available optimisers for ammonia plants are provided by M/s Haldor Topsoe A/S, M/s ICI, M/s MTI etc. These consultants guarantee typical energy savings of about 1% because of incorporation of optimiser in an existing plant. However, proper evaluation of the running plant should be carried out before taking a decision of installing an optimiser to ascertain feasibility.

6.0 Conclusion

It can be concluded that there is ample scope for improving energy efficiency through improvements in design aspects and by achieving better performance of ammonia plants. Continuous efforts should be on for improving energy efficiency of ammonia plants by adopting energy conservation schemes. However,it may be stressed that only proven and reliable schemes should be considered as unreliable measures can more than offset the benefits. Also modification to improve the reliability should be given due preference as the improvent in reliability can give large amount of benefits. Last but not the least, it should be borne in mind that energy conservation is not a one man or one day affair, but should be taken as a habit by one and all.

Energy Conservation in Urea Process Plant

K K Chaturvedi
National Fertilizers Limited, Panipat

Energy Conservation in Urea Process Plant

1.0 Introduction

Fertilizer industries are highly energy intensive. About 80% of the total variable cost of production is on account of energy in the form of coal, oil and power. This is all the more important keeping in view the limited resources of energy available in the country and in the World as a whole. Under the existing conditions of globalization, with exorbitant hike in the cost of energy, conservation of energy cannot be avoided.

The major inputs contributing to the total energy consumption are coal, fuel oil, power for oil based plants. If the consumption of these inputs can be lowered by efficient use to produce same amount of Amm./Urea, then productivity vis-a-vis profitability will increase. A detailed calculation is given in table I, which clearly shows that the profits increase to a great extent even by a marginal reduction of various energy inputs. This signifies the importance of energy conservation in urea plant processes.

Three basic types of urea processes are in use in the world today. In the conventional total recycle process, the synthesis loop and carbamate decomposition/separation stages are separate, allowing the synthesis reactor to be run at the highest possible pressure (in practice about 250 bar) for maximum conversion. The unreacted ammonia and carbon dioxide are separated in two or three stages operating at progressively lower pressures. In each stage, carbamate in the product solution is decomposed by heat exchange with steam at the appropriate temperature level, and the ammonia and carbon dioxide given off are cooled and reabsorbed into a less concentrated carbamate solution, which has been recycled from the succeeding stage, in a so called carbamate solution is then pumped to the proceeding stage vapors from the final (low pressure) decomposer are scrubbed with process condensate before being released, and the lean solution produced is what is used in the low pressure carbamate condenser. Solution from the highest pressure carbamate condenser is pumped to the synthesis reactor, along with the ammonia and carbon dioxide reactants, which increase its carbamate content to the working level. Imported steam at medium pressure is used to supply the heat for the carbamate decomposers, while lower grade steam (about 4 bar) is raised from the heat of neutralization in the succeeding carbamate condensers. This steam mostly cannot be utilised within the urea plant and is therefore available for export at the battery limit.

The total recycle process is effective, but it is complicated and used a lot of equipment every stage has a carbamate decomposer and separator, a carbamate condenser, a solution pump, and ancillary equipment. The latter includes equipment needed to handle steam at various pressure, although in some processes the process solution provides most of the process heating and cooling.

The stripping processes, which today dominate the urea world, were developed with not only simplicity and capital cost savings but also energy efficiency in mind. They are based on the principle that carbamate can be induced to decompose to a large extent without lowering the total pressure if the partial pressure of one of the decomposition products (ammonia or carbon dioxide) in the decomposer is reduced. Since the partial pressure of a constituent of a gas mixture depends on its concentration, this can be achieved by sweeping the carbamate decomposer with a large volume of another gas. This could be an inert gas, which would lower the concentration of both the decomposition products but would subsequently have to be separated from them, but almost he same effect can be achieved by using one or other of them. That means that the urea synthesis and the bulk of the carbamate decomposition occur at the same pressure. Thus, the carbamate decomposer and condenser have to be large enough to accommodate the extra gas flow. As the carbamate condenser operates at the full synthesis loop pressure it also runs at a higher temperature, so that a major part of the heat of formation of the carbamate is produced at a higher grade than in the total recycle process. However, because stripping efficiency is adversely affected by pressure, the synthesis loop is run at a somewhat lower pressure than in total recycle processes, so the per pass conversion is somewhat lower. There are two commercial pure stripping processes: one (Stamicarbon) uses carbon dioxide as the stripping gas and the other (Snamprogetti) uses ammonia.

Now that the main patents on the principles of the ammonia stripping and carbon dioxide stripping processes have expired, the conventional total recycle processes have mostly been superseded and their licensors have incorporated feature of both stripping and total recycle into their current process schemes. TEC MTC, ACES process, Montedison's IDR urea process, UTI's heat recycle urea process are some of them.

2.0 NFL Panipat

NFL Panipat operates 900 tpd ammonia plant based on shell gasification and 1550-tpd urea plant based on M/s. MTC total recycle C-improved process. Plant started commercial production in 1979. Since commissioning of the plant, capacity utilisation has increased over the years and after 18 years of operation it has given record production in the year 1996-96. On stream days have also increased and plant capacity utilisation has also increased to 120%.

3.0 Approach to energy management

As Energy consumption in a plant depends on productive as well as unproductive losses, two-fold approach is being applied to contain the losses at NFL Panipat.

First step in energy management is to reduce the unproductive losses. The factors effecting the unproductive losses are

a) On Stream days
b) Capacity utilisation
c) No. of start-up & shutdowns

By proper operation and maintenance management, high capacity utilisation and on stream days have been achieved and No. of start-up and shutdowns have been brought down. The steps taken in this regard are:

3.1 Cooling water treatment

Better management of cooling water treatment has resulted in low corrosion and fouling levels. Exchanger breakdowns have reduced and shutdown for cleaning the exchangers every year can be avoided.

3.2 KT/UT tank recovery

Start up and shutdown solution, Reactor solution during shutdown and solution during prilling shutdown is stored in these tanks. As per design these were to be recovered in III cycle and crystallizer. Due to high ammonia, their recovery was consuming long time and load reduction. Higher capacity pump was installed to recover this solution in LP cycle. This reduced the recovery time and thus no effect on load. Also Reactor solution transfer time, during start-ups, reduced from 8 hrs. to 4 hrs.

3.3 Proper maintenance practice

Maintenance jobs are planned in advance by doing preventive checking of equipments, proper inventory control and thereby reducing the maintenance days in a year.

3.4 Ammonia feed pump modification

Ammonia feed pumps were having frequent problem in discharge safety valve. Maintenance on this account was quite high. Resonators were installed and SV was shifted to down stream of this resonator. Vibrations have reduced considerably and maintenance on account of SV have come down drastically. Flow transmitter or pressure transmitter tapping failure has not been noticed since then.

These factors have directly effected the Energy scenario at NFL Panipat. Figure I shows that from a Energy Consumption level of 1.73 MKcals/Te. Of urea in the year 1990-91 we have come down to 9.468 MKcal/Te. Urea in the year 1995-96, which is also expected to improve in the years to come.

Figure II also shows that at NFL Panipat on stream days improved from 290 to 331 and energy consumption level came down accordingly.

From Figure.I it is clear that by increasing capacity utilisation from a meager 85% to 103% and by reducing number of start up and shutdowns from 55 to 45 energy consumption levels have come down drastically. Plant has also given 1870 Te/day of production on sustained

Any improvement in the urea technology involves the following:

- Reduction in power consumption required for pumping the reactants into synthesis reactor
- Reduction in steam consumption for decomposing the unconverted carbamate.
- Recovery of heat evolved during condensation of gaseous mixture.
- Reduction in power consumption for recycling carbamate solution to reactor.
- Minimising dust losses and pollutant concentration in liquid effluent.

Total Energy = Energy input as Ammonia+ Energy input as Steam+ Energy input as Power+Energy consumed for Cooling Water circulation.

85-90% of the total energy comes in the form of Ammonia. 85-90% of the rest energy input comes from steam. So, even a minor change in their consumption effects the total energy consumption to great extent as is evident from Table I.

By improving plant operation and maintenance practices and implementation of minor major modifications, low energy consumption levels have been achieved. Measures taken during last few years to reduce energy consumption and improve the productivity are described below

4.0 Measures taken to reduce dust losses & ammonia/urea losses

4.1 Electronic weighing machine

During bagging, weight variation to the tune of 100 to 200 gms. was normal and at times, it was increasing as high as 500 gms. per bag with the earlier machines. This was deliberately being kept on higher side to avoid complaints regarding low weight of bags. Electronic machines with a data logger were installed in the year 1994-95. After their installation, weight variations are being restricted to + 50 gms. only, thus saving urea of an amount equal to 1000 Te./year.

4.2 *Acoustic granulators*

Normal choking problems was observed in the spray nozzles of the earlier design. These were required to be washed frequently to remove choking. This was putting restriction on Prilling Tower capacity. Due to these nozzles, lots of size variation of prills was observed and dust generation and agglomeration was quite common. Agglomerations were being dissolved and recycled back consuming Energy for recycle. Dust generations was resulting in higher load on dust chamber and foam filters. This was reducing life span of foam filters. These were requiring change over atleast three times in year. Also Urea bearing solution in higher quantity was being generated in dust chamber.

To overcome these problems, Acoustic Granulators were installed in the year 1995. After their installation, Prill size has become uniform and load on dust chamber has also reduced. One and a half set of filters is now required per year. Also capacity of the Prilling Tower has increased to more than 125%. Cleaning frequency is being kept once in 12 days. Urea losses have also reduced.

4.3 *CFD raker*

Prilling Tower bottom is having a 'continuous fluidised dryer (CFD)' Prill from prilling tower falls on it. Due to heap formation and poor fluidization, air flow in the prilling tower is getting affected. This also results in lump formation. These lumps are to be dissolved and recycled back consuming Energy. Also, twice in a month washing was required to clean the surface of the CFD resulting in plant outage and effluent generation, in turn reducing capacity utilisation
consumed in crystallizer for urea recovery. But, its consumption was varying depending on crystal density. Also on higher loads, when dust chamber overflow was more, this could not be consumed fully and lot of urea was being lost in effluent.

It was decided to recover this solution in LP Absorber as make up, in place of fresh condensate being used earlier. An underground tank was built to collect this urea solution from dust chamber A pump with strainers in its discharge was put and lines were connected to LP Absorber and crystallizer with control valves in each line. Due to this modification, all the solution is either recovered in crystallizer or in LP absorber Loss of urea is thus avoided.

4.4 *Washings, gland leakages & seal flushing water recovery*

Earlier, all these washings, gland packing and seal outlets were connected to effluent pit and were being sent to Effluent Treatment Plant. After the installation of underground tank, all this urea bearing effluent is also diverted to this tank and is being recovered in crystalizer or LP absorber.

thus reducing urea losses. Also, CFD washing is done with the underground tank solution. Resulting in reduction in urea losses from urea bearing effluent.

4.5 Off gas absorbent tank (OGAT) solution

As per design vapours from gas separator operating at 0.3 K/Atm. Pressure are being condensed and then absorbed in Off Gas Absorber (OGA). Inerts coming out of OGA are mixed with air, and through a blower used as stripping medium in the Atm. Portion of the gas separator. A bleed Press. Control valve is provided at the discharge of the blower. Condensed Vapours are collected in OGAT, mixed with fresh condensate and fed to the top of the OGA for final absorption. But, as the concentration of OGAT Solution was high, inerts coming out of OGA were containing high ammonia and urea droplets. This was resulting in ammonia losses through the bleed vent and also in poor performance of the blower.

System was modified to divert the fresh condensate to the top of OGA directly and divert OGAT solution to LP absorber mixed with OGA solution. This resulted in better absorption of Ammonia in OGA and also eliminated urea carry over to the blower. Ammonia in the blower suction came down from 0.5% to less than 0.1%. Stripping in gas separator also improved.

4.6 Ammonia feed pump depressurisation

As per design, Ammonia feed pumps for handing over to Maintenance were being depressurised into OGA. This resulted in high Ammonia concentration in OGA and losses through blower vents. Also OGA being an Atm. Vessel, process was taking long time for handing over to pump. Procedure was modified and liquid ammonia from the pumps is now pushed back to Ammonia reservoir through bypass line by feeding Nitrogen gas at the downstream of suction valve. Once all the ammonia is pushed out, Nitrogen gas is stopped and pump is depressurised in OGA for the recovery of residual ammonia. This not only has reduced Ammonia losses, load on OGA but also has reduced handing over time for maintenance

Above measures have resulted in lower specific consumption of Ammonia per tonne of Urea. Specific consumption has dropped from an exorbitant 0.594 te te of Urea in the year 1985-86 to 0.583 te te of Urea in 1995-96. In continuous running of the plant, specific consumption of 0.575 te te of Urea is also achieved.

5.0 Measures taken to reduce steam consumption

85-90% energy consumption in urea plant is contributed by steam. Steam is utilised for these purposes, mainly,

- For pumping/compressing reactants & recycle solution.

- For decomposing the unconverted carbamate.
- For concentration of aqueous urea solution.
- For heating and flushing.

To some extent consumption can be reduced by adopting better recovery methods for heat evolved in the reaction and their recovery during condensation of gaseous mixture . But, such a heat recovery is at a lower temperature level and requirement of higher-grade steam is not effected. Efforts are thus necessary to minimise the requirement of higher-grade steam. Measures taken at NFL, Panipat are as follows:

5.1 CO_2 booster compressor

CO_2 Booster compressor is centrifugal and compresses CO_2 gas from 0.1 kg/cm^2 to 30 kg/cm^2 and feeds it to main CO_2 Compressor which is reciprocating and is motor driven. This booster is driven by a turbine, which is extraction/condensing type and operates with inlet steam of 40 Kg/cm^2 and extraction of 12 Kg/cm^2. On continuous monitoring of this compressor, it was observed that steam consumption was on higher side and its inter stage efficiencies were less. It was also putting limitations in increasing the plant load. Three steps were taken to improve the performance of this compressor:

⇒ Its suction pressure was increased to 0.18 kg/cm^2 from its design value of 0.1 kg/cm^2.

⇒ To arrest inter stage bypassing through the parting planes, grooves were made on the parting planes and rubber rings were provided.

⇒ To avoid frequent leakages and for achieving better inter stage temperatures, inter coolers tubes were replaced with stainless steel and better cooling water management was followed.

Due to these steps, compressor efficiency increased and load limitation was over come. Loads upto 125% plant load could be achieved. Also, steam saving of 4-5 Te/hr. was achieved.

5.2 Mother liquor recycle

A part of the mother liquor from urea centrifuges was being recycled to the Reactor for controlling the biuret content of the product. As per design, 10 Te/hr. of mother liquor containing 70% urea was recycled through LP absorber. As biuret content of the product was only 0.3% this recycle was stopped. Biuret thus increased to 0.4%. But, this resulted in 7% reduction in recycle solution flow and 4% load reduction in Urea Reactor.

5.3 *Desuperheater in 12K steam header*

As per design 40 to 12K steam desuperheater was using cold condensate at 40°C. Modification was done to supply 90 °C condensate to the desuperheater. For catering to the higher load requirements, additional desuperheater was provided. This resulted in steam savings of 0.6 Te/hr.

5.4 *Heating coil in mother liquor tank*

As per design, temperature in the mother liquor tank was being maintained by using a steam coil with 4K steam. Hot condensate from the flash drum was connected to this tank for heating.

5.5 *Trap-man*

Monitoring of all the steam traps is being carried out regularly with the help of 'Trapman' and faulty traps are attended to steam leakages are also being promptly attended by isolating the lines or with the help of 'Fermanite'.

5.6 *Air heater condensate line modification*

Air heater is having two parts In the first part, air is heated with condensate from flash drum and in the second part, air temperature is maintained by utilising 4K steam. As per design, Level Control valve of flash drum was located upstream of Air heater which resulted in flashing of condensate and thus lower temperature and two phase flow Due to two phase flow, tubes were getting damaged and Air temps could be achieved by consuming steam also. This LCV was shifted downstream of Air heater. This resulted in steam saving and avoiding tube leakage. All these measures have resulted in lowering the steam consumption to as low as 1.2 te per te of urea on continuous basis.

6.0 Measures taken to reduce power consumption

Though impact of power consumption on total energy consumption in urea process is very less but conservation of power has sufficient contribution in energy conservation as a whole. Measures taken at NFL Panipat are as follows

6.1 *Ammonia booster pump*

Ammonia booster pump feeds ammonia from ammonia reservoir to Ammonia feed pumps. At higher loads limitation was faced in its capacity. Also its discharge pressure was bearing Ammonia vapor pressure in summer resulting in damages to Ammonia feed pumps. Two pumps were normally run to overcome this problem.

Its impeller size was increased from 287 mm to 320mm and a higher capacity motor was installed. Increase of discharge pressure and capacity of the pump was achieved. This resulted

in running of only one pump and power reduction in main Ammonia feed pumps. Breakdowns on main ammonia feed pumps are reduced. Saving of 338 MW per year was achieved.

6.2 Dust chamber spray nozzles

For scrubbing in prilling tower dust chamber 36 nozzles were in position as per design. Water was circulated in this chamber to achieve a concentration of 16 to 18% of urea. At increased prilling loads, to achieve proper dust recovery two pumps were being run.

These nozzles were replaced with modified smaller nozzles and their number also increased to 72 in place of 36. After installation of these nozzles circulation flow reduced but scrubbing efficiency increased due to better distribution area. One pump running thus became sufficient. Also higher concentration of circulation water (rr-24%) could be achieved. Down stream foam filter life also improved. Saving of 724 MW per year was achieved.

6.3 Power factor improvement

compressor is synchronous driven. A 2.2 MW 11 KV driven motor is used. Its power factor was maintained around 0.89 as recommended. After consultation with the supplier its power factor was raised to 00.98-0.99. This resulted in lowering of power consumption in this motor as well as improving the power factor of total system. 155 MW power per year was thus saved.

6.4 Cooling water

To keep check on power consumption in cooling water circulation following steps were taken:

- Cooling tower efficiencies are monitored on a regular basis. Any bypassing in the tower is attended at the earliest opportunity Tower packing are also repaired replaced during annual turn around.
- Cooling water pump efficiency is calculated and repairs are done at the earliest.
- Fouling factors of the exchangers are monitored and cooling water treatment adjusted accordingly.

This monitoring has resulted in running of less number of pumps and fans, and better heat transfer in exchangers. Due to above measures and by avoiding/reducing running of motors during shutdowns lot of saving in power consumption was achieved.

7.0 Conclusion

Urea process technology has undergone tremendous change from the days of I generation recycle plants when energy consumption was 1.8 MKcals/Te. of urea this came down to 1.0 Mkcals/Te. of urea in III generation recycle plants and has further come down in modern plants based on stripping technology.

90% of specific energy per te of urea is consumed in the form of ammonia and thus any energy conservation measure in urea plant focuses attention on the rest of 10% of the total energy. Improvement in on stream days, capacity utilisation and reduction in interruptions has direct impact on energy consumption.

It has been estimated that proper energy management can lead to 10-15% saving in the short and medium term with low requirement of capital investment. With systematic planning and CO_2 commitment it is possible to operate old plants in line with the modern plants.

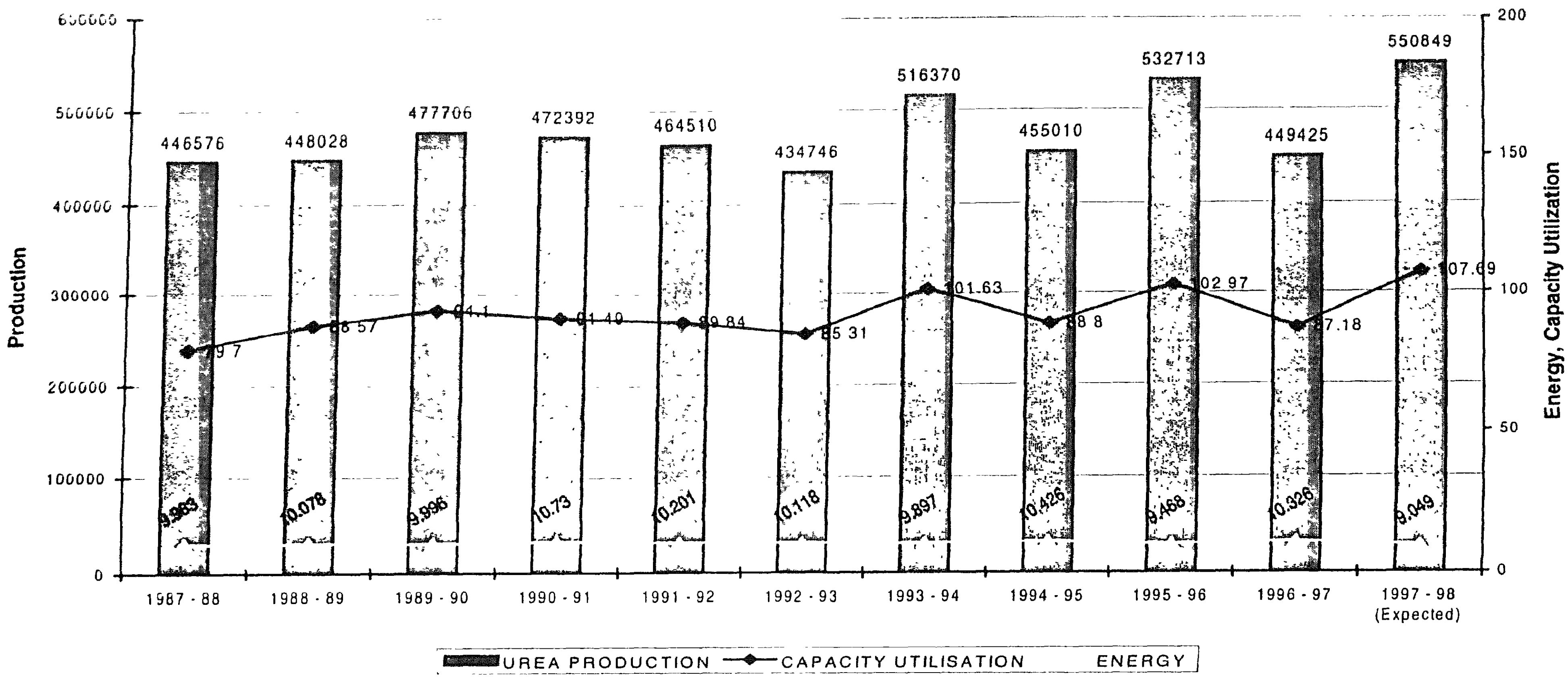
At NFL Panipat, number of measures has been taken and these have resulted in improvement in almost all the factors contributing to Low Energy Consumption. Best figures of 0.977 Mkcal/Te. of urea on monthly basis have been achieved. The process is continuing and we expect to improve further in years to come.

TABLE - I

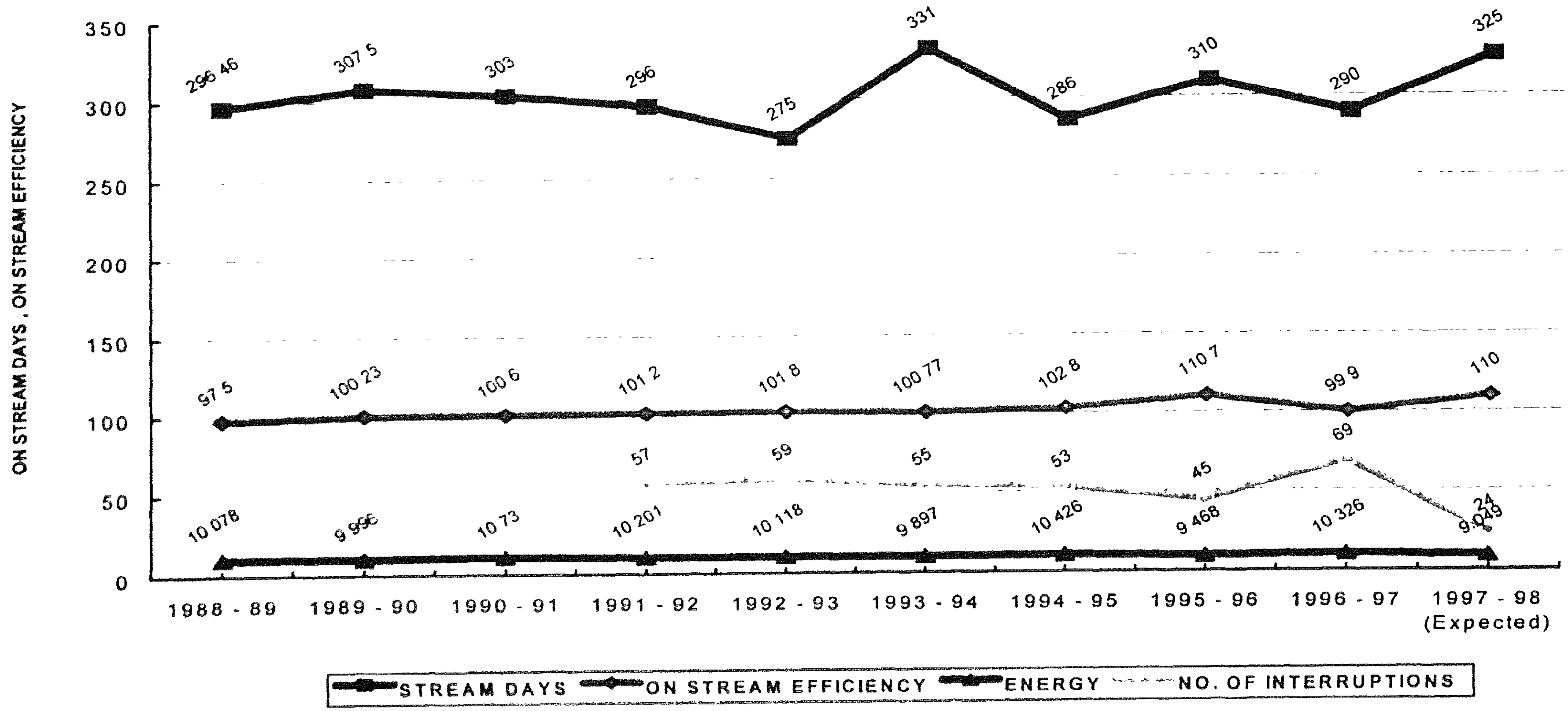
EFFECT OF REDUCTION IN VARIOUS INPUTS ON ENERGY CONSUMPTION

INPUTS	AMMONIA		STEAM		POWER	
	Te	Energy Mkcal/Te	Te	Energy Mkcal/Te	MWH	Energy Mkcal/Te
Consumption per te	0 587	7.631	1 223	0.917	0.125	0 1075
If consumption is lowered by 1%	0.581	7.5547	1 211	0.908	0.1238	0.1064
Difference	0 00587	0 07631	0.01223	0 0092	0.00125	0.0011
Savings Mkcal/Day		118.28		14 26		1 705
Savings Mkcal/year		39033		4706		562
Financial Savings per year		~200 lakhs		~25 lakhs		~3 lakhs

UREA PLANT PERFORMANCE
FIGURE I



UREA PLANT PERFORMANCE
FIGURE II



Environment Norms and Pollution Abatement Measures in Fertilizer Industry

Dr (Ms) B Swaminathan
Fertiliser Association of India (FAI), New Delhi

Environment Norms and Pollution Abatement Measures in Fertilizer Industry

1.0 Introduction

Protection of the Environment from Pollution is important not only for developed countries but also for developing countries. Industrialization, which is essential for development and economic growth of a country, can endanger the public health, ecology and water resources, unless proper measures are taken to control pollutants emitting from the industries as well as from other sources.

The fertiliser industry has been one of the fast growing industrial sector in India. Today India rank as the third largest producer and consumer of fertiliser in the world, next only to China and USA There are 59 major Nitrogenous and NP/NPK Complex Fertiliser Plants besides 83 Single Superphosphate Plant with an installed capacity of 9 468 Million MT of N and 3.165 Million MT of P2O5. The capacity and production of fertilisers since 1950's is given in Table 1.

Table 1. Capacity and production of N & P2O5

(000 tonnes)

Year	Capacity	Production	Capacity	Production
1951-52	90	29	78	10
1961-62	283	154	182	65
1971-72	1.487	949	534	290
1981-82	4,719	3,143	1,408	950
1991-92	8,282	7,302	2,806	2 562
1992-93	8.510	7,431	2,798	2 321
1993-94	8,844	7,231	2 817	1,874
1994-95	8,998	7,944	2,873	2,563
1995-96	9,134	8,769	2 982	2 593
1996-97	9,468	8.593	3,165	2.571

These production figures show the spectacular growth and development of Indian Fertiliser Industry during the last two decades. Realising that development unless accompanies by environmental consideration would not be sustainable, the Fertiliser industry accorded Environmental Protection high priority. Fertiliser plants have been taking significant and positive steps to control and minimise the release of pollutant from fertiliser production to the

environment. In order to protect the environment from the effects associated with the fertiliser manufacture, fertiliser industry adopted a systematic approach towards total Environment Management. Further, adoption of sound management practices like planning, organisation, innovative attitude, good house keeping were also undertaken.

2.0 Environmental Norms

Pollution control to preserve the environment is universally practised mainly through the evolution of environmental protection standards, their implementation and taking legal action against those violating them. The environmental protection standards are essential to ensure that the pollutants discharged from the industry into the environment are within the capacity of the environment to assimilate through the natural process of self purification.

In India the first legislation came into existence in 1974 specially to protect water component of the environment called the Water (prevention and Control of Pollution) Act, followed by The Air (Prevention and Control of Pollution) Act 1981 in respect of air component of the environment. The Environment (Protection) Act, 1986 and umbrella act covering all facets of environment, and The Public Liability Insurance Act, 1991 to provide immediate relief to the person(s) affected by accidents occurring while handling any hazardous substance.

The Environment (Protection) Rules notified under Environment Protection Act, 1996 had laid down industry specific standards for both emission and discharge of effluent in respect of about 60 categories of industries including the fertiliser industry. The Environmental Protection Standards laid under EP Rules for straight nitrogenous fertilisers and phosphatic fertilisers are given in Tables 2 and 3 respectively and are the same as the minimal National Standards (MINAS) as specified under the Water/Air Act. From Table 2, it is clear that two different sets of standards are in force - one for plants commissioned prior to January, 1982 and one for plants commissioned after January 1, 1982. The EP Act does not specify any separate standards for effluents used for irrigation or disposed into sea or injected into soil etc.

The Ambient Air Quality standards in respect of noise is given in Table 4. The ambient air quality standards prescribed for various categories of areas in respect of suspended particulate matter (SPM), SO_2, NO_x and carbon mono-oxide (CO) as given in Table 5. The waste water generation standards for the fertiliser industry are given in Table 6.

Table 2. EPA standards for nitrogenous fertilisers

	Parameters	Concentration in the effluent not to exceed milligramme per litre (except for pH)	
		Plants commissioned Jan.1, 1982 onwards (a)	Plants commissioned prior to Jan.1,1982 (b)
(I)	Liquid Effluents		
(a)	Straight Nitrogenous Fertilisers, excluding the Calcium Ammonium Nitrate and Ammonium Nitrate and Ammonium Nitrate Fertiliser		
	ph	6 5-8 0	6 5-8 0
	Ammoniacal Nitrogen	50	75
	Total Kjeldahl Nitrogen	100	150
	Free Ammoniacal Nitrogen	4	4
	Nitrate Nitrogen	10	10
	Cyanide as CN	0 2	0 2
	Vanadium as V	0 2	0 2
	Arsenic as As	0 2	0 2
	Suspended solids	100	100
	Oil and Grease	10	10
	* Hexavalent Chrom as cr	0 1	0 1
	* Total chromium as cr	2 0	2 0
To be complies with at the outlet or chromate removal unit			
(b)	Straight Nitrogenous Fertilisers including Calcium Ammonium Nitrate and Ammonium Nitrate Fertilisers	Concentration of all parameters in the effluents remain the same except nitrate nitrogen Concentration of nitrate nitrogen in the effluent not to exceed 20 milligramme per litre	
II	**Gaseous Emissions** Parameter Urea (Particulate matter emissions)	Prilling Tower Commissioned after 1 1 82 50 mg per normal cubic metre 0 5 kg per tonne of urea	Prilling Tower Commissioned prior to 1 1 82 150 mg per normal cubic metre 2 kg per tonne of urea

Table 3. EPA Standards for Phosphatic Fertilisers

Parameters	Concentration in the effluents not to exceed milligramme per litre (except for pH)
(I)(a) Liquid effluents	
a) Straight Phosphate Fertilizer	
pH	7 0-9 0
Phosphate as P	5
Oil and Grease	10
Suspended Solids	100
* Floride as F	10
** Hexavalent Chromium as Cr	0 1
** Total Chromium as Cr	2 0

* To be complied with at the outlet of fluoride removal unit If the recipient system so demands, fluorides as F shall be limited to 1 5 mg/1.

** To be complied with at the outlet of chromate removal unit

	Concentration in the effluents not to exceed milligramme per litre (except pH)	
b) Complex fertilisers excluding Calcium Ammonium Nitrate, Ammonium Nitrate & Ammonium Nitrophosphate Fertilizers	Plants commissioned on Jan 1,1982	Plants Commissioned prior to Jan 1,1982 (b)
pH	6 5-8 0	6 5-8 0
Ammoniacal Nitrogen	50	75
Free Ammoniacal Nitrogen	4	4
Total Kjeldahl Nitrogen	100	150
Nitrate Nitrogen	10	10
Cyanide as CN	0 2	0 2
Vanadium as V	0 2	0 2
Arsenic as	0 2	0 2
Phosphate as P	5	5
Oil and Grease	10	10

	Suspended Solids		
	* Fluoride as F	10	10
	** Hexavalent Chrom as cr	0.1	0.1
	* Total chromium as cr.	2.0	2.0

* To be complied with at the outlet of fluoride removal unit. If the system so demands, fluoride as F shall be limited to 1.5 mg/l.

** To be complied with at the outlet of chromate removal unit.

c)	Complex fertilisers including Calcium Ammonium Nitrate, Ammonium Nitrophosphate Fertilisers	Concentration of all parameters in the effluents remain the same except nitrate nitrogen, concentration of nitrate nitrogen in the effluent not to exceed 20 milligramme per litre.	
III)	Gaseous Emissions		
a)	Phosphatic fertilisers (fluoride and particulate matter emission)	Phosphoric acid manufacturing unit Granulation, mixing & grinding of rockphosphate	25 milligramme per normal cubic metre as total fluoride. 150 milligramme per normal cubic metre of particulate matter
b)	Nitric Acid (emission of Oxides of Nitrogen)	Emission of Oxides of Nitrogen	3 kilogramme of Oxides of Nitrogen per tonne of weak acid (before concentration) produced.
c)	Sulphuric acid (emission of sulphur dioxide and acid mist)	Sulphur dioxide emission	4 kilogramme per tonne of concentrated (one hundred per cent) acid produced. 50 milligramme per normal cubic metre.

Table 4. Ambient Air Quality Standards in Respect of Noise

Area code	Category of area	Limits in dB(A) Leg. day time	Limits in dB (A) Leg. Night time
(A)	Industrial area	75	70
(B)	Commercial area	65	55
(C)	Residential area	55	45
(D)	Silence Zone	50	40

Note 1 Day time is reckoned in between 6 a.m. and 9 p m.

Note 2 Night time is reckoned in between 9 p.m. and 6 a.m

Note 3. Silence zone is defined as area upto 100 metres around such premises as hospitals, educational institutions and courts. The silence zones are to be declared by the competent authority. Use of vehicular horns,loudspeakers and bursting of crackers shall be banned in these zones.

Note 4 Mixed categories of area should be declared as one of four above mentioned categories by the Competent Authority and the corresponding standards shall apply.

Table 5. Ambient Air Quality Standards

		Concentration in ambient air			Method of measurement
		Industrial Area	Residential Rural & other areas	Sensitive area	
1	2	3	4	5	6
Sulphur Dioxide (SO_2)	Annual Avg.	*80 ug/m^3	60ug/m^3	150ug/m^3	Improved west & Gaeke method
	24 hours**	120ug/m^3	80ug/m3	30ug/m^3	Ultra violet flourescence
Oxides of Nitrogen as NO_2	Annual Avg.* 24 hours**	80ug/m^3	60ug/m^3	15ug/m^3	Jacob & Hochheiser modified (Na. Arsenic Method. Gas phase chemilumina scence

Suspended Particulate Matter (SPM)	Annual Avg.* 24 hours**	360ug/m^3 500ug/m^3	140ug/m^3 200ug/m^3	70ug/m^3 100ug/m^3	High Volume sampling (Avg. Flow rate not less than 1.1m^3/min.)
Respirable Particulate matter (size less than 10 um) (RPM)	Annual Avg.* 24 hours**	120ug/m^3 150ug/m^3	60ug/m^3 100ug/m^3	50ug/m^3 750ug/m^3	Respirable particulate matter sampler
Lead (Bb)	Annual Avg.* 24 hours**	1.0ug/m3 1.5ug/m^3	0.75ug/m^3 1.00ug/m^3	0.50ug/m^3 0.75ug/m^3	AAS Method after sampling using EPM 2000 or equivalent filter paper
Carbon Monoxide (CO)	8 hours** 1 hour	5.0mg/m^3 10.0mg/m3	2.0mg/m^3 4.0mg/m	1.0mg/m 2.0mg/m^3	Non dispensive infrared spectroscopy

* Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.

** 24 hourly 8 hourly values should be met 98% of the time in a year. However 2% of the time, it may exceed but not on two consecutive days

Table 6. Waste Water Generation Standards for Fertiliser Industry

Category		Quantum of Water
1	Straight nitrogenous fertiliser	5 MP ton or urea equivalent produced
2	Straight phosphatic fertiliser (SSP & TSP) excluding manufacture of any acid	0.5 MP ton of SSP of TSP
3	Complex fertiliser	Standards of nitrogenous and phosphatic fertilisers are applicable depending on the primary product

3.0 Implementation by the Fertiliser Industry

The Indian Fertilizer industry has adopted a whole range of fertiliser technologies and is a mix of several old vintage plants and modern plants with the latest technology. The fertiliser industry has performed exceedingly well on Environment Protection Standard compliance front, in spite of operating several old vintage plants and also the Indian Environmental Protection Standards being as stringent as those of developed countries. On the 59 Nitrogenous and NP/NPK plants barring 3 plants accounting for less than 1.0% nitrogen production during 1996-97, all other plants are complying with Environmental Protection Standards (EPS). Non complying plants are sick units and would have to be revamped with substantial investment to comply with EP Standards. In the SSP sector, 44 of the 53 major plants accounting for more than 93% of the SSP production during 1995-96 were complying with EP Standards. In spite of operating several old vintage plants, the performance of fertiliser industry on Environmental Protection Standards compliance front has been exceedingly good. From the above it is clear that Environment Legislation have influenced the choice of technology and resulted in improved operation of plants and consequently better environmental performances.

Further, realising the fact that conservation of natural resources is essential for the preservation of the environment, the Fertiliser Industry, which is a large consumer of water, endeavoured to conserve water and promote its efficient use. In a span of seven years, fertiliser plants as a whole reduced its water consumption in NH_3 - urea plants by 27% and in NP/NPK complex fertiliser plants with integrated phos-acid production facility by over 40%. Also the waste water discharged by Fertiliser plants is well within the stipulated standards.

Greater efficiency in production or reduction in consumption of energy contributes significantly to resource conservation and pollution abatement. Thus, efforts made towards reducing energy consumption with a view to improve overall cost effectiveness of the fertiliser plant also helped conserve feedstock and abate pollution. Over 9 years period from 1987-88 to 1996-97, the weighted average energy consumption for ammonia production reduced by 1.6 G Cal per tonne and to that extent the natural gas/petroleum feedstock have been conserved and also the environmental impact of utilisation of the energy sources reduced. Further the weighted average specific consumption of ammonia for urea production improved from 0.591 MT/MT of Urea during 1988-89 to 0.587 MT/MT of Urea during 1995-96. This means reduction in plant losses to the environment.

Thus besides cleaner technologies, the adoption of more efficient technological process geared towards greater energy efficiency and production efficiency have also helped in preventing pollution at source. In other words, all these technological developments have led to cleaner production, which is a departure from the traditional method of controlling pollution through treatment and disposal. Some of the major technological developments adopted/modifications carried out which helped fertiliser industry to abate pollution are discussed below.

4.0 Nitrogenous Fertiliser

4.1 Ammonia

In general, harmful emission from an operation could be reduced in four different ways namely, changing over to cleaner fuel, cleaning the fuel before the combustion, controlling emission and using existing fuel more efficiently by adopting advanced high efficiency low emission technology. In India, four different feedstocks namely, natural/associated gas, naphtha, fuel oil and coal are used for the manufacture of ammonia and intermediate for nitrogenous fertiliser production. For the same energy production, oil released about 1.5 times the amount of CO_2 released by natural gas, while coal releases about twice the CO_2 as that of natural gas. It is generally known that CO_2 gas emitted primarily from the burning of fossil fuel is responsible for climatic warming and the onset of green house effect. Consequently, natural gas is the least polluting. Also relative energy consumption per tonne of ammonia production is the least for natural gas followed by naphtha, fuel oil and coal. Relative investment for ammonia plant based on different feedstocks could be the following order:

Feedstock	Relative Investment
Natural Gas	1
Naphtha	1.15
Fuel Oil	1.5
Coal	1.8

The relative energy consumption for ammonia plant based on these feedstocks also follow the same order. Relative energy consumption/te ammonia production based on feedstocks is of the following order:

Feedstock	Relative Energy Requirement
Natural Gas	1
Naphtha	1.1
Fuel Oil	1.15
Coal	1.45

With the availability of gas reserves in Bombay high and South Bassein Regions, natural gas/Associated gas emerged as predominant feedstock. The share of natural gas in the annual installed capacity increased from 13% in 1980 to 53.9% in 1997. The shift in feedstock usage

has thus helped in reducing the overall pollution load. Capacity of Nitrogen(N) based on various feedstock for the year 1980 and 1997 is given below.

Capacity of Nitrogen (N) - Feedstock wise:

Feedstock	**% of capacity based on various feedstocks**	
	As on 1980	As on 1997
Natural Gas	13.0	53 9
Naphtha	51.7	24.5
Fuel Oil	19 6	11 9
Coal	9.9	3.1
Coke Coke Oven Gas & others	1.4	1.5
Ammonia (Ext. Supply)	2.7	5.1
Electric Power *a*	1.7	--

a Only a part of the capacity is based on electrolysis

In order to address both in process and end of the process add on pollution abatement technologies, let us first identify the source of pollution in a typical ammonia plant. The process flow diagram (Figure.1) indicate the pollutants associated with each step in the manufacture process of ammonia.

The first step in the production of ammonia is the desulfurisation of feedstock Since sulphur is a poison to the reformer catalyst, the sulphur content of natural gas/naphtha must be reduced to less than 0.5 ppm. Either activated carbon beds with metallic additives or zinc oxide beds are used for desulfurisation. Activated carbon, if used, has to be regenerated once in 20 days by passing super heated steam Air is also added which reacts with metal sulphides regenerating the metal oxide and elemental sulphur. So during regeneration sulphur, carbon monoxide and hydrocarbons are released However, this emission only occurs once in 20 days and therefore, this source is not considered to be a problem and there is no control device for this source When zinc oxide catalyst is used for desulfurisation it absorbs sulphur upto 18-20% by weight and is replaced about once a year rather than regeneration. the use of zincoxide beds results in appreciable energy saving and minimal environmental impact Given below are the level of SO_2 emission from the primary reformer stacks of some of the ammonia plants

Plant	SO_2 emission
Nagarjuna Fertilisers	traces
IFFCO Aonla	traces
KRIBHCO	<0.01 ppm
Indo-Gulf Ferts. & Chems.	traces
SFC	<0.2 ppm
ZACL	traces

In the primary reformer section, the combustion of natural gas naphtha fuel oil produces NO_x, hydrocarbon, particulates etc and are emitted from primary reformer stack. To date there are no NO_x emission standards for primary reformer stack under EPA although several State Pollution Control Boards have stipulated standards. To control emission of NO_x from primary reformer stack and also auxiliary boilers due to firing of fuel, special low NO_x burners are available and are used by some plants. NO_x, SPM & hydrocarbon emission from two of the new gas based plants are given below:

Plant	NO_x Emission	SPM	Hydrocarbon
KRIBHCO	2.5 ppm	NT	NT
INDO-GULF FERTS & CHEMICALS	1.3-2.5 ppm	NT	NT

Several processes of CO_2 removal namely Benfield, Catacarb, Vetrocoke, MEA etc. are available and used in ammonia plants. In Vetrocoke process arsenic oxide is used as additive in absorbent solution. Although plants have total recycle system, arsenic waste is produced from occasional blowdown. So plants having arsenic based CO_2 removal process switched over to other processes. However, in the new Vetrocoke CO_2 removal process, the arsenic oxide has now been replaced by glycine. Indo-Gulf Fertilisers and Chemicals, and the new gas based plants which have been commissioned recently, have opted for glycine based Vetrocoke CO_2 removal system.

In the CO_2 removal section, the CO_2 absorbed is regenerated by stripping with steam and the stripped solution is reused for CO_2 absorption. In CO_2 stripper, preheated Benfield overhead condensate at 83 °C is introduced at the top of the stripper and the process condensate from shift convertor is introduced at the bottom of CO_2 stripper. The CO_2 is

stripped by mean of steam partly generated by depressurisation of process condensate. The stripped condensate leaves the CO_2 stripper at the bottom and is introduced into the process condensate stripper in which impurities like CO_2, NH_3 and methanol are stripped off by means of L.P steam. The gaseous overhead was earlier injected into primary reformer stack to abate pollution. However, while this reduced overall plant emission of ammonia and methanol, NO_x emission owing the conversion of NH_3 into NO_x significantly increased. In the modified system, the gaseous overhead is condensed and refluxed to the stripper. A small portion of reflux liquid which is rich in NH_3 and methanol is purged out and send to reformer where they undergo steam reforming to produce synthesis gas. In this way, emission from condensate stripper and CO_2 section is completely eliminated. The stripped condensate after polishing is used as boiler feed water. This eliminates an effluent stream and also reduces the DM water requirement by a proportional amount.

In the synthesis gas section about 6% of the gas is purged from synthesis loop to prevent the buildup of inerts like methanol, Argon, Helium etc. in the circulating gas and was used for firing reformer. Since the purge gas contains significant amount of NH_3 and hydrogen, firing of reformer with purge gas leads to significant increase in NO_x emission from the primary reformer stack. Recovery of hydrogen and ammonia from the purge gas can increase the ammonia production by 5-7% without increase in feedstock consumption. Consequently, purge gas recovery units were installed. Recovery of NH_3 and hydrogen from the purge gas, in addition to increasing the NH_3 production also eliminated a source of NO_x emission in the reformer stack due to firing of reformer with purge gas. The energy conserved due to purge gas recovery is of the order of 0.2-0.25 million kilo calories per tonne of ammonia produced.

Typical emission from the reformer stack of a gas based ammonia plant with purge gas recovery unit is as given below:

Pollutant	Actual analysis (ppm)
SPM	NT
HC	NT
SO_2	<0.01
NO_x	2-5
H2S	NT

In ammonia plants based on fuel oil, approximately 2% of the total carbon input to the gassifier is left unburnt and is recovered by qnenching the gas with water. Built-in pollution abatement systems are provided for recovery of carbon from carbon slurry produced by quenching. The carbon from the slurry is seperated by treating it with naphtha and/or fuel oil.

The carbon oil so produced is recycled back to the gassifier. In texaco process there is total internal recycling of the unburnt carbon to the process, while in shell process only 80-90% of the carbon oil are recycled to the gassifier. Balance is burnt in the boiler. During startup and stabilisation of plant, the entire quantity of carbon slurry is not utilised. The unutilised carbon slurry is stored in lagoons. The dry carbon from the lagoons are mixed with coal and burnt in boilers of steam generation plant.

The carbon slurry produced during gasification also contains HCN(approximately 80 ppm) Consequently HCN stripper are installed in fuel oil based plants to remove HCN from the waste water stream. The Cyanide bearing wastes are subjected to air oxidation to reduce cyanide to the level of 2 ppm and the residual cyanide is brought down to 0.2 ppm by alkaline chlorination. Chlorine demand for other contaminants like H2S, ammonia, carbon etc., is almost eliminated by simulating favourable condition

In ammonia plants based on fuel oil, gaseous emission are generated from two sections namely, the rectisol wash unit and liquid nitrogen wash unit. The gaseous steam generated from the rectisol wash unit contains 30 to 35% hydrogen sulphide. This stream is treated in the sulphur recovery unit using the modified Claus process to produce 99.9% pure elemental sulphur Gases free from hydrogen sulphide are vented to the atmosphere. In the liquid nitrogen wash unit, the bleed of from the main stream containing 30-40% carbon monoxide is used as boiler fuel. In one of the fertiliser plant, this carbon monoxide bearing waste gas is used for producing formic acid, an import substitute chemicals

4.2 Urea

As mentioned earlier, ammonia is the intermediate for the production of urea. Any reduction in the specific consumption of ammonia for urea production means reduction in plant losses to the environment i.e. lesser pollution. Obviously, any improvement or development aimed at reducing feed consumption is bound to succeed in reducing pollution The progress in urea production technology parallels the growth in urea production and is reflected by the improvement in the average designed specific consumption from 0.589 for plants commissioned on or before 1970 and 0.581 for plants commissioned during 1976-80 to 0.575 for recent plants. The lowest specific consumption per tonne of urea achieved by any Indian plant is 0.573 as against the weighted average of designed and actual specific consumption of 0.579 and 0.587 (achieved during 1995-96) respectively for all the plants and the stoichiometric figure of 0.565. The losses from urea plants in the form of NH_3 and urea and the sources of emission and effluents are indicated in Figure 2

In the process of urea synthesis, air is introduced for passivation. The lower the amount of passivation air required by a process, lower will be the inert flow rate and lower the amount of NH_3 released to the atmosphere. So processes that require lower amount of passivation are preferable. Usually, the inerts from the recirculation section are scrubbed in

inert wash column to recover ammonia and then led to prilling tower top. In fact no gas is vented from urea plant without scrubbing. Since inerts contain oxygen and hydrogen, constant analysis is done to check that the explosive limit of the gases is not exceeded.

The largest source of liquid pollution in urea plant is process condensate formed in concentration section. The water formed during urea synthesis is evaporated under vacuum in concentrator/evaporater. The evaporated process water is condensed in surface condensers. The uncondensed gas from the surface condenser is vented to the atmosphere through off gas scrubber where NH_3 and CO_2 along with inerts are finally absorbed under atmospheric pressure. The process condensate containing about 4-7% ammonia and 0.7-1.0% urea is treated in urea hydrolyser stripper. The process condensate is first fed to the top of distillation column. In the stripping column, free ammonia and carbon-dioxide is distilled. A stream from the middle of distillation column containing mainly urea and traces of ammonia and CO_2 is tapped off and sent to hydrolyser. In the hydrolyser, the solution from the stripping column is heated directly by steam to hydrolyse urea into ammonia and carbon- dioxide. Process condensate from hydrolyser outlet is fed back to the distillation tower where ammonia and CO_2 are stripped off with low pressure steam. The stripped process condensate containing about 2 ppm urea and 5 ppm ammonia is used as Boiler Feed Water after polishing. The overhead products of distillation column and hydrolyser are condensed in overhead condenser and is refluxed partly to the distillation column and partly to the L.P condenser for its reuse.

The process condensate from the urea plant containing urea and ammonia is also treated in Urea Biohydrolyser. In this unique biological treatment, a specially developed ureolytic mixed culture converts urea nitrogen into ammoniacal nitrogen. At the outlet of bioreactor, the urea nitrogen is less than 50 ppm. The effluent from the urea biohydrolyser is fed to stripper for NH_3 removal.

In many of the fuel oil based plants, the process condensate is first stripped off ammonia and then subjected to conventional biological nitrification and dentrification process for urea hydrolysis.

One of the major source of dust emission is the urea prilling tower. The prilling towers is either forced draft or natural draft type. The natural draft prilling tower is designed for an effective free fall height of 75 feet to minimise particulate dust emission (maximum dust content of 40 mg/NM3) as against forced draft prilling tower. By and large plants commissioned prior to 1.1.82 are forced draft prilling tower while the newer plants have natural draft prilling tower. In addition, in new plants dedusting system could be provided at the top of prilling tower to bring down the emission level further to 15 mg/Nm3. The dedusting system consists of two stages scrubbing system and has provision for circulation of lean urea solution for dust scrubbing and demister flushing. The circulating urea solution solution of about 10% urea concentration is recirculated to urea process. The treated effluent in urea as makeup for this system. Further, the conical bottom of prilling tower prevents attrition of prills at the bottom and hence the powder urea dust formation in urea production and also belt and conveying system. In old generation plants with forced draft prilling tower,

the prilling towers have been equipped with the dust collector of porous resin construction with a mist eliminator and water washing of urea dust to minimise dust emission. Installation of acoustic granulator has also helped in reducing dust level considerably.

Lot of urea dust is emitted during product handling like falling from one conveyor to another, screening, delumping, bagging etc. To recover the dust, wet dedusting systems are installed. In the dust recovery system urea particles suspended in the air stream are dissolved into water The system is designed for inlet dust concentration of 8 gm/M3 of air and outlet dust concentration less than 50 mg/M3 of air. Urea solution of 2-3% concentration from the dedusting system is recirculated in the plant.

Fertiliser industry is a large consumer of water. Water is required for cooling purpose and as boiler feed water. Due to limited availability of fresh water of good quality, water used in cooling has to be treated. The type of treatment adopted for circulating cooling water is depending upon make-up water. The major problems associated with circulating cooling water systems are corrosion, scaling, fouling and micro biological growth In order to overcome the problems of corrosion and scaling, cooling water is treated with chromate. However, the effluent generated from the cooling tower has to be treated to remove chromate since hexavalent chromium is toxic The removal of chromate is carried out by reduction of chromate with FeSO4 under acidic conditions followed by precipitation using lime. The chromate sludge is stored in lagoons. Yet another cooling water treatment system based on phosphate is available To prevent generation of toxic chromium sludge some plants have switched over to non-chromate cooling water system.

5.0 Phosphatic Fertilisers

The phosphatic fertiliser comprises of NP/NPK complex fertilisers and single super phosphate The NP/NPK complex fertiliser plants are usually associated with sulphuric acid and phosphoric acid, or nitric acid plants. Some of the NP/NPK plants are based on imported phosphoric acid

5.1 Sulphuric Acid

Sulphuric acid is produced from sulphur. Most of the fertiliser plants have adopted Double Conversion Double Absorption(DCDA) process for sulphuric acid production DCDA process can achieve 99.5 percent conversion efficiency. The increase in conversion efficiency leads to increased production and also reduced SO_2 emission.

The average SO_2 emission per tonne of sulphuric acid from all the 8 sulphuric acid plants associated with the fertiliser plants has steadily come down from 2.2 kgs during 1988-89 to 1.45 kgs during 1994-95 as against environmental protection standards of 4 kgs SO_2 per tonne of sulphuric acid.

5.2 *Phosphoric Acid*

Phosphoric acid is produced by digesting finely ground rock phosphate with sulphuric acid In the manufacture of phosphoric acid fluorine liberated at various stages of manufacture are recovered by scrubbing in specialised scrubber by water and dilute alkali.

The fluorine removal efficiency is over 95% and most satisfactory The hydroflurosilicicacid formed is recirculated to the rock phosphate digester or used for the manufacture of AlF3/Cryolite/Na2SiF6 etc.

Considerable quantity of rock phosphate dust is regenerated from the grinding mill. Bag filters or wet de-dusting system are provided in the rock phosphate handling grinding and conveying section for reduction of dust emission.

5.3 *Nitric Acid Plant*

Tail gas from the nitric acid plant containing unabsorbed oxides of nitrate are the main source of emission. Extended absorption and chilling process have been adopted to reduce NO_x concentration in the tail gas and increase acid production. Catalytic reduction is most widely accepted NO_x abatement process. This involves the addition of one vessel containing catalyst and NO_x can be reduced to less than 500 ppm. The NO_x concentration can also be reduced by scrubbing the tail gas with caustic soda/soda ash to produce sodium nitrite or nitrate. One of the latest nitric acid plant has used mono pressure process and installed high efficiency absorbers. With this the NO_x emission has been reduced to less than 200 ppm.

India has 3 nitrophosphate plants with associated nitric acid plants. The NO_x emission from an old nitric acid plants was of the order of 1.6 kg NO_x per tonne of HNO3 during 1995-96 as against the EP Standard of 3 kg per tonne of nitric acid, while the NO_x emission from the more recent plant is of the order of only 0.2 kg per tonne of nitric acid.

For the concentrated nitric acid production, technology based on magnesium nitrate is available. The advantage of this process is that the waste water can be recycled to nitric acid absorber which is not possible with sulphuric acid process. Also the requirement of treatment plant for denitrification has been eliminated.

DAP NP NPK Complex Fertiliser. Under normal operation of the plant no liquid effluent is generated in DAP plant. Fumes of ammonia and small quantity of fluorine compounds are generated from neutralisation and granulation operation. These fumes are scrubbed with dilute phosphoric acid and the gaseous containing residual contaminants are discharged through stack. The emission of dust takes place in the drying screening and cooling section. These dusts are also scrubbed with dilute phosphoric acid and let out through stack.

The average SPM emission in kgs per tonne of P2O5 from 15 NP/NPK plants have come down from around 3 kgs during 1988-89 to about 1 kg during 1995-96 while Fluorine emission is of the order of 0.04 kg per tonne P2O5.

5.4 Nitro Phosphate

The effluent from nitro phosphate plant contains ammoniacal nitrogen, phosphates, fluorides, nitrate nitrogen, suspended solid etc. and requires series of treatment for removal of pollutants. The liquid effluent from Nitro Phosphate is first sent to equalising tanks to avoid shock loading and then subjected to air stripping to remove ammoniacal nitrogen. Further the phosphate and fluorides are removed in two stages with lime. Finally the nitrate is removed from the effluent by biological denitrification. A source of organic carbon is provided in the reactor and specially cultured bacteria breaks nitrate and nitrite to nitrogen and oxygen which escapes to atmosphere.

Ammonia is generated in neutralisation section and calcium nitrate to ammonium nitrate conversion section. Separate scrubbing columns are provided in each of the section to remove ammonia vapour. Dilute nitric acid (60% concentration) is used as the scrubber medium which reacts with ammonia to produce ammonium nitrate and is recycled. Flouride bearing gases and oxides of nitrogen are generated in rock dissolving section and neutralisation section, while oxides of nitrogen are also generated in inert. section and crystallisation section. These gases are scrubbed in specially designed scrubbing columns. NO_x removal is carried out depending on the concentration of NO_x bearing gas. Liquid effluent from the scrubber is then treated in effluent treatment plant.

6.0 Conclusion

The Indian Fertiliser Industry has kept pace with the developments in taking preventive and control measure to protect and improve the quality of the environment The technical solutions adopted have been so chosen as to solve the problem of specific pollutants entirely and not transfer the pollutants from one media to other like from air to water and vice versa The fertiliser industry has thus strived to ensure a total solution to the problem of pollution through technological developments and improved design features and minimised pollution to socially acceptable level. This lecture note is intended to provide a brief overview on industrial energy conservation.The broad issues that are touched upon include, (i) the potential of energy conservation in the Indian industrial sector, (ii) the policy recommendations, (iii) the barriers to implementing energy conservation measures, (iv) The incentive schemes and (v) The role of energy audit in industrial energy conservation. The participants might find some of the items repetitive as these issues are discussed in many forums But for the benefit of everybody and also for the purpose of continuity, the issues are highlighted as a background to the other write ups presented in this document

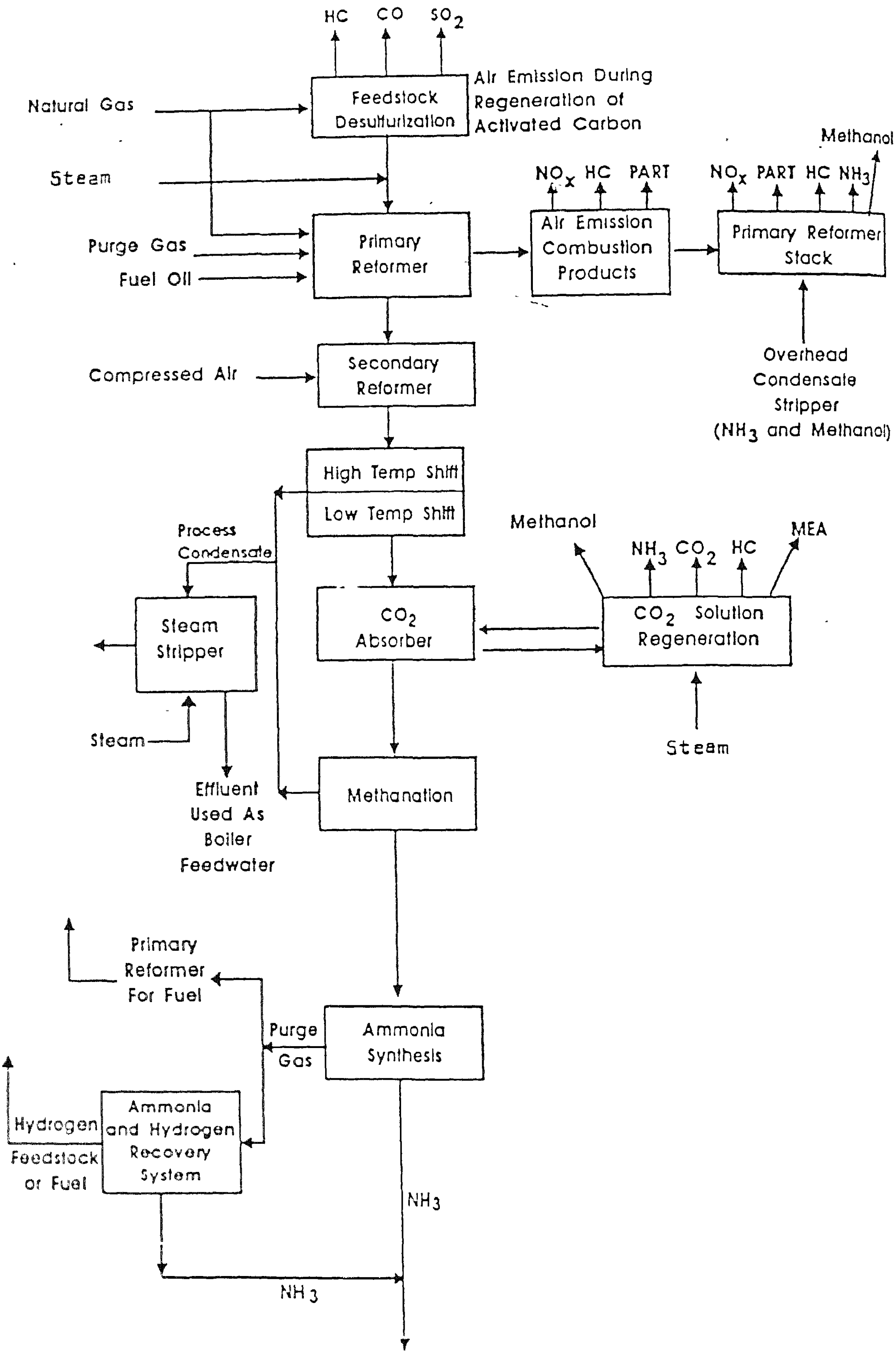


Fig. 1 : Process Flow Diagram for a Typical Ammonia Plant With Pollutants Associated with Each Process

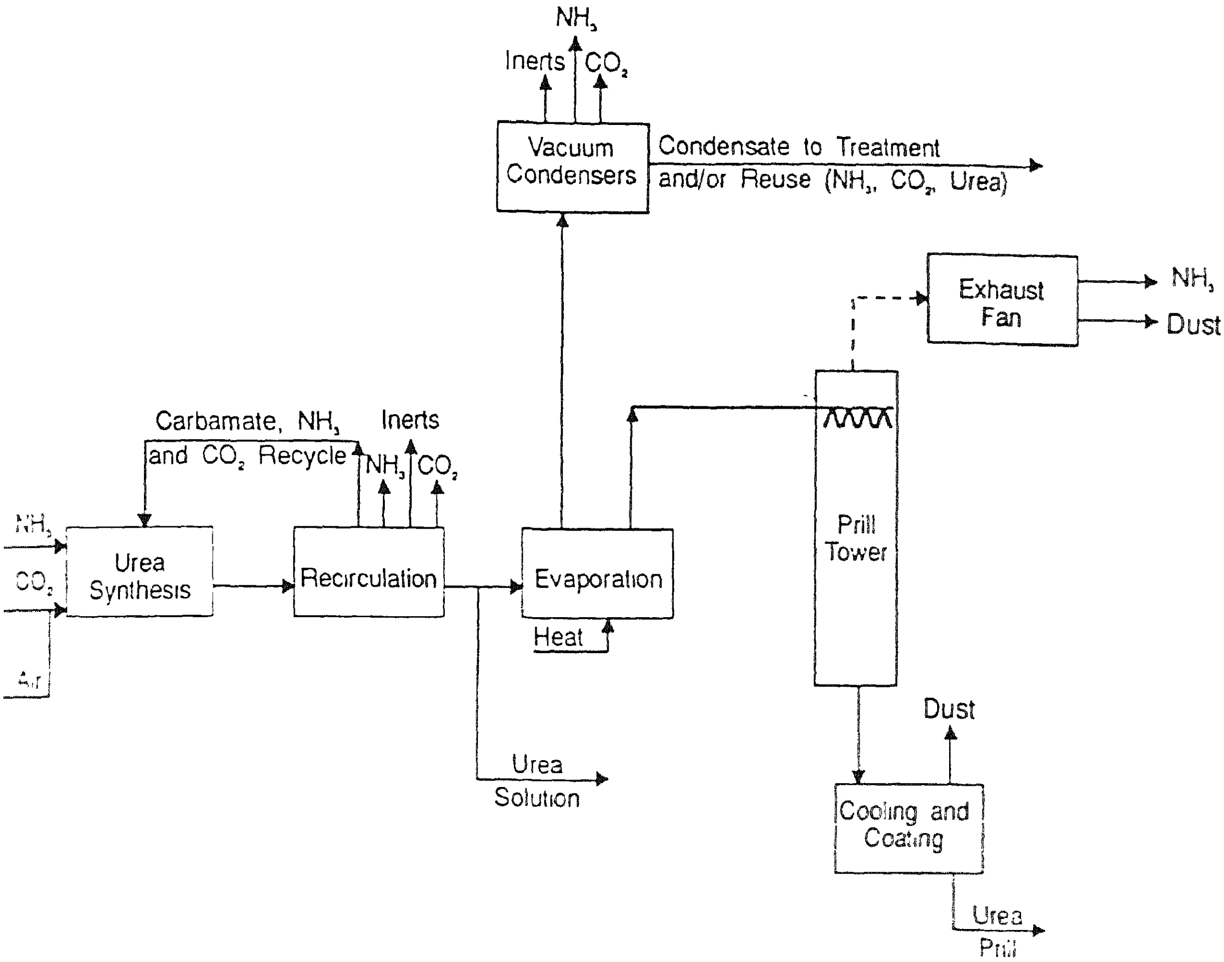


Figure 2: Process Flow Diagram for a Typical Urea Plant, Showing Pollutants Associated With Each Process.

Pinch Analysis in Ammonia and Urea Process Plant

M O Garg
Kinetic Technologies India Limited (KTI)

PINCH ANALYSIS IN FERTILIZER COMPLEXES

PROCESS SYSTEMS SERVICES DIVISION
KINETICS TECHNOLOGY INDIA LIMITED
NEW DELHI

TRAINING PROGRAMME ON
ENERGY EFFICIENCY AND ENVIRONMENT IMPROVEMENT IN FERTILIZER INDUSTRY
21 - 23 JANUARY 1998

A MANNESMANN COMPANY

PRESENTATION OVERVIEW

- INTRODUCTION TO PINCH TECHNOLOGY
- TOTAL SITE ANALYSIS
- APPLICATION TO FERTILIZER COMPLEXES
- CONCLUSIONS

INTRODUCTION TO PINCH TECHNOLOGY

KTI
A MANNESMANN COMPANY

- TRADITIONAL APPROACH BASED ON EXPERIENCE
- MATHEMATICALMETHOD
- THERMODYNAMIC METHOD

TRADITIONAL APPROACH

- LARGELY BASED ON HEURISTICS OR PREVIOUS DESIGN EXPERIENCE
- SEVERAL ALTERNATIVES NEED TO BE GENERATED AND SIMULATED TO ESTABLISH THE BEST
- POSSIBILITY OF SUB-OPTIMAL DESIGN

MATHEMATICAL METHOD

- FORMULATE THE DESIGN AS A MATHEMATICAL OPTIMIZATION PROBLEM
- REQUIRES HIGH DEGREE OF MATHEMATICAL SKILL AND PROGRAMMING EFFORT
- LITTLE OR NO PHYSICAL INSIGHT - USE OF BRUTE FORCE

THERMODYNAMIC METHOD

PINCH TECHNOLOGY

- USER-DRIVEN APPROACH IN THE DEVELOPMENT OF ENERGY AND PROCESS SYSTEMS
- SET ENERGY AND CAPITAL TARGETS BEFORE DESIGN
- ANALYSIS BASED ON PHYSICAL INSIGHT

PINCH TECHNOLOGY APPROACH

A MANNESMANN COMPANY

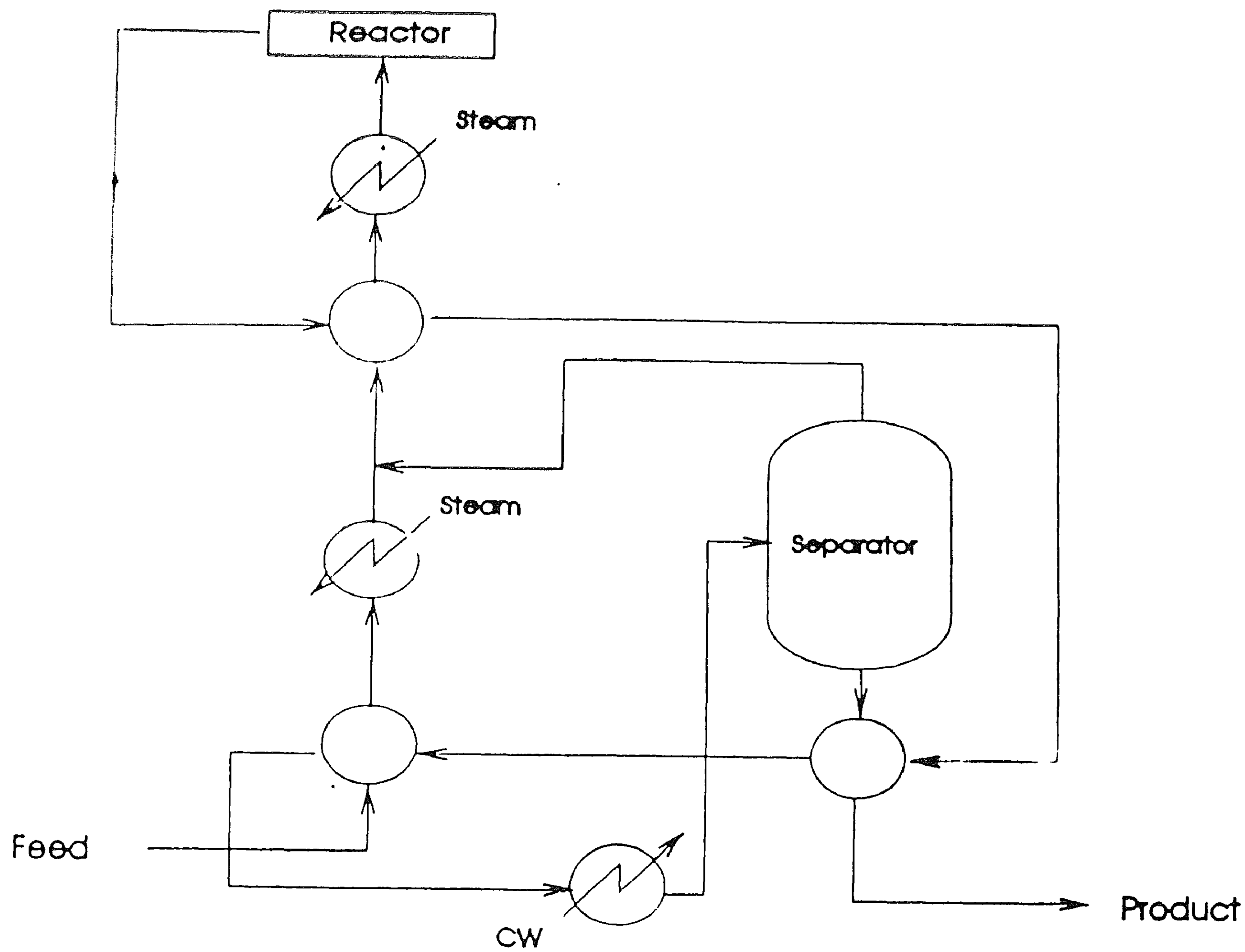
PINCH TECHNOLOGY TOOLS

- COMPOSITE CURVES
- GRAND COMPOSITE CURVES
- AREA vs ENERGY PLOT

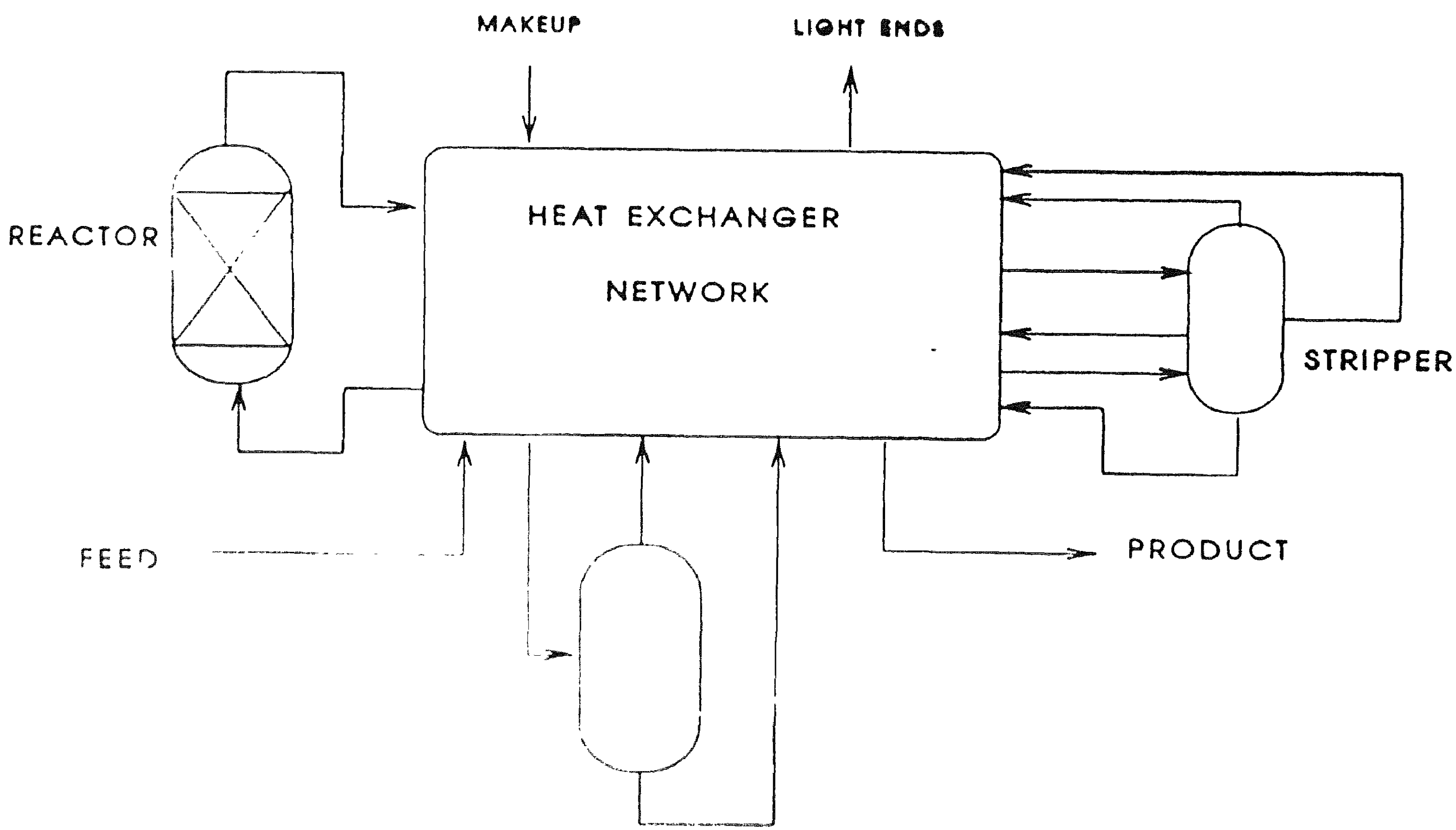
KTI

A MANNESMANN COMPANY

A TYPICAL PFD

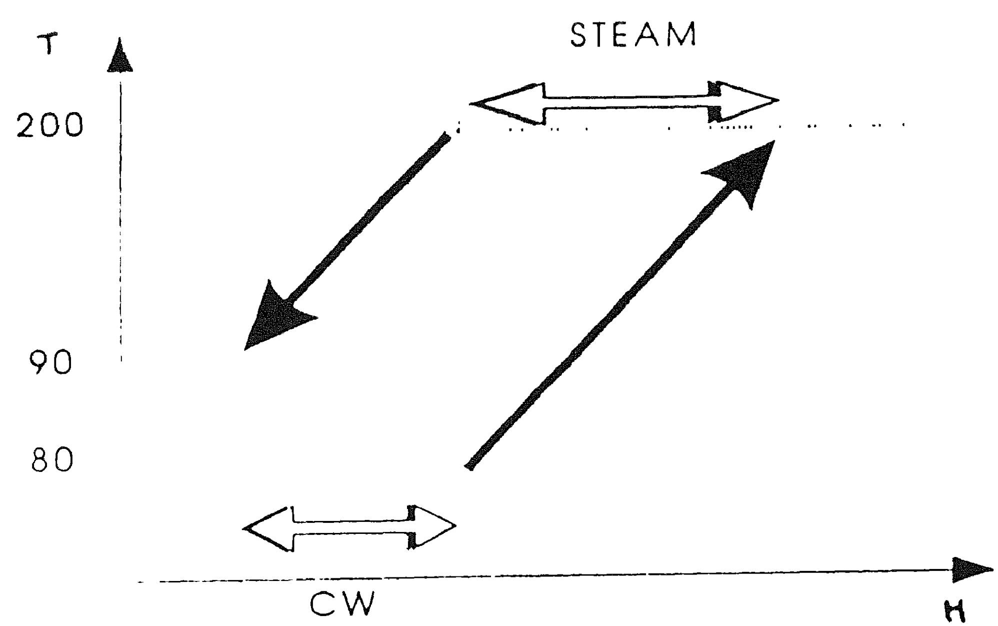


GENERAL PROCESS PLANT

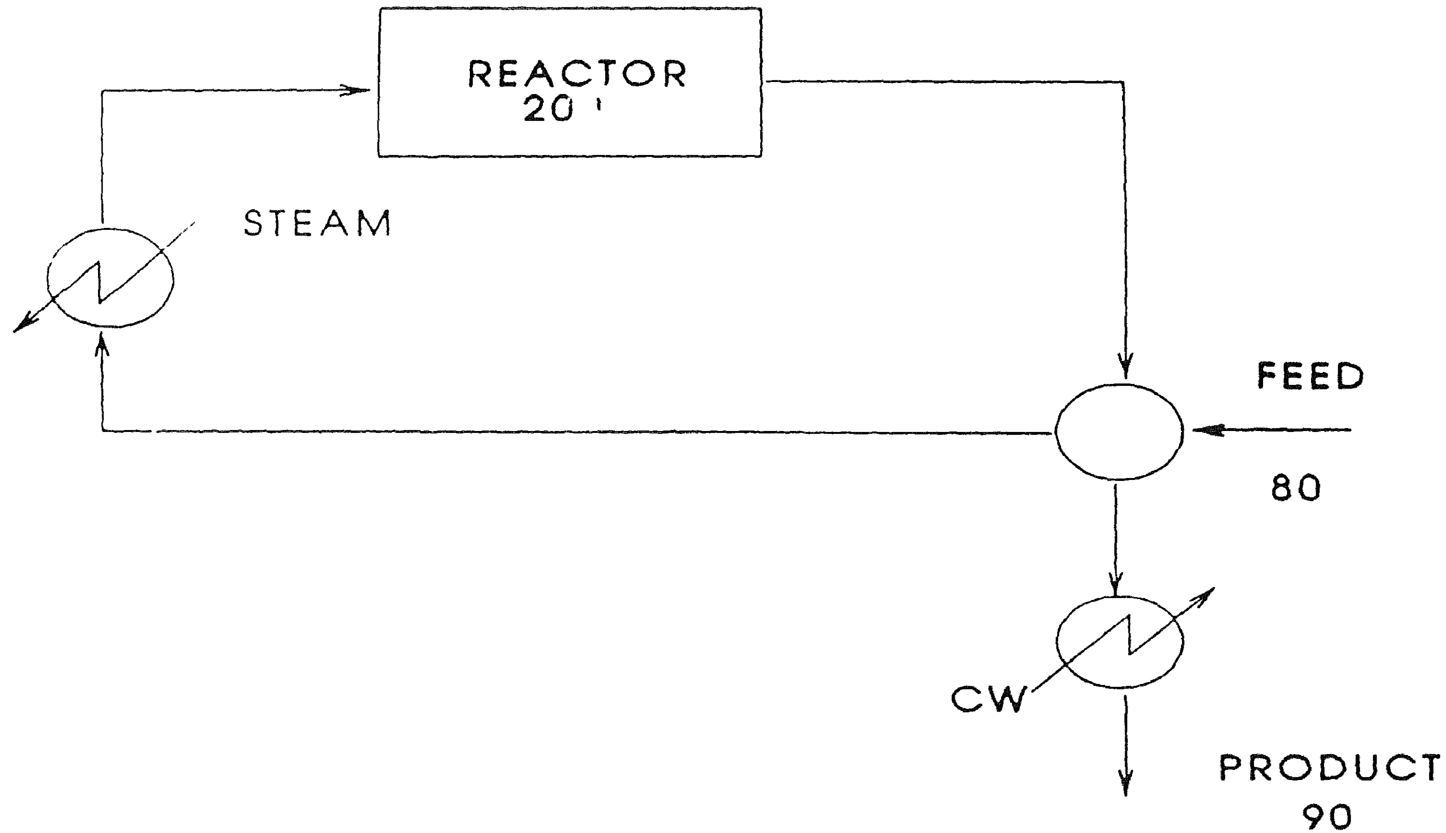


CONSIDER THIS SIMPLE PROCESS ...

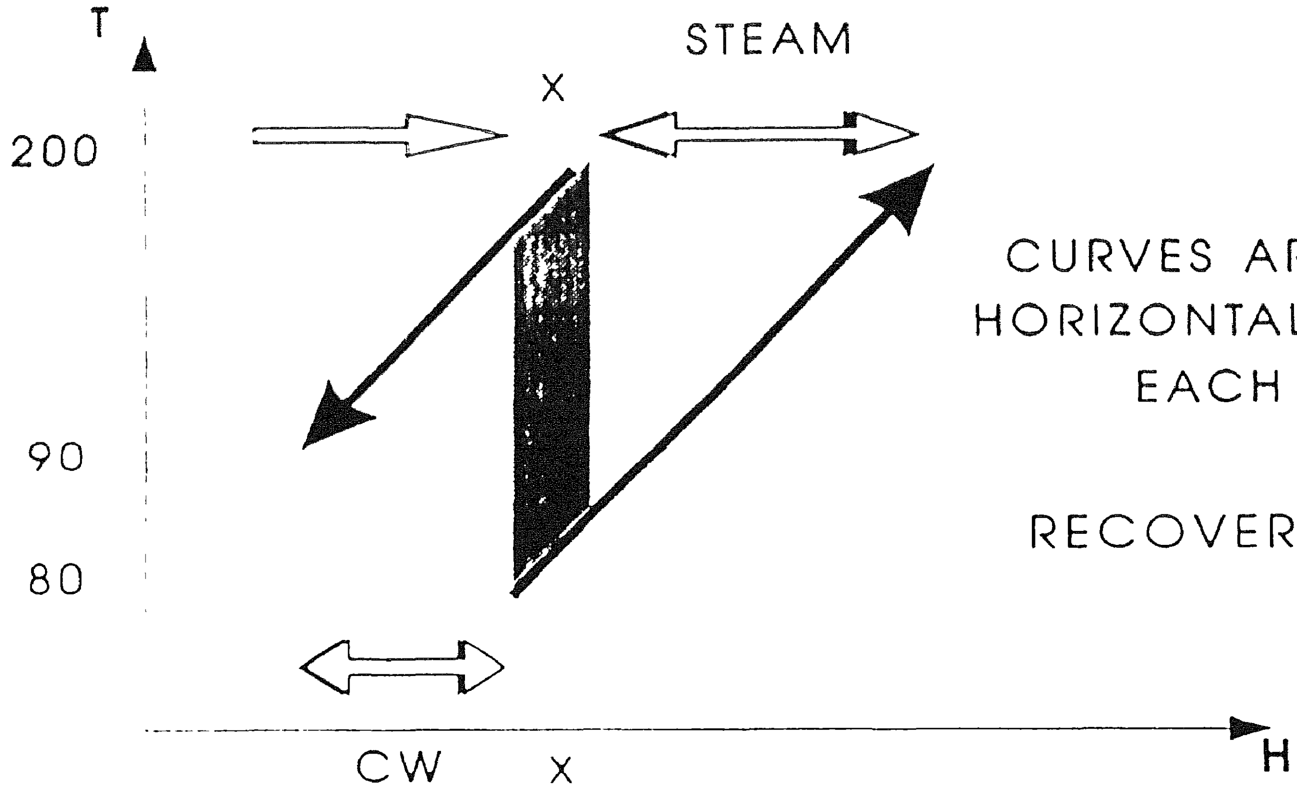




IMPROVED DESIGN ...



PROCESS HEAT EXCHANGE REDUCES BOTH STEAM AND COOLING WATER

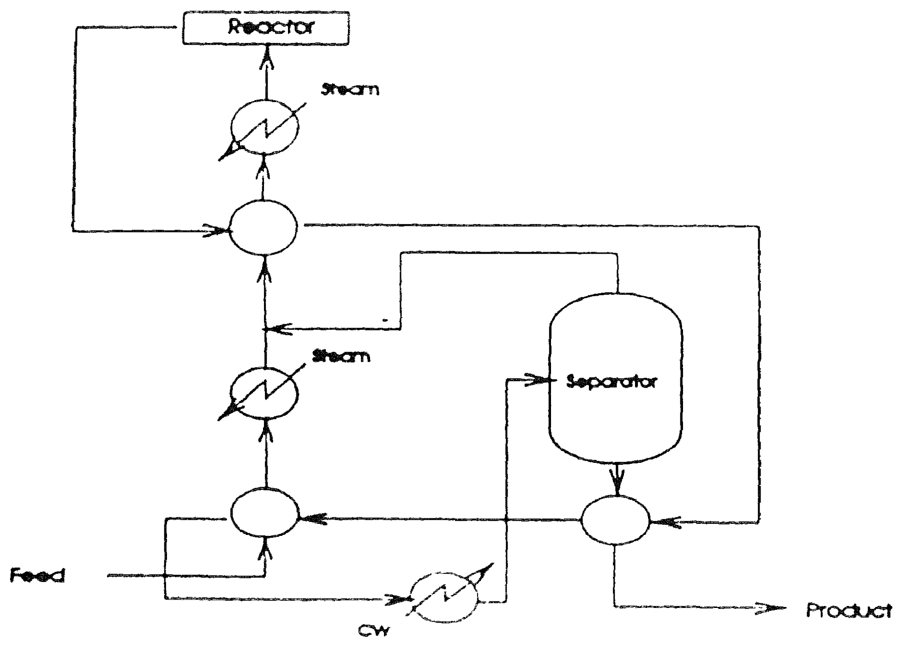


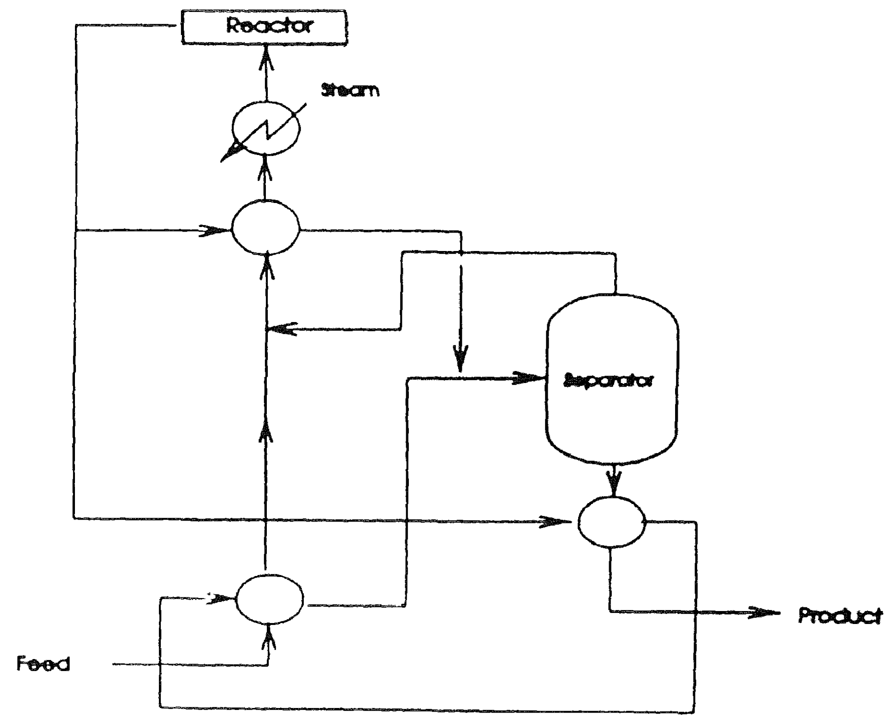
CURVES ARE 'SHIFTED' HORIZONTALLY TOWARDS EACH OTHER

RECOVERED HEAT = X

KTI

DESIGN COMPARISON FOR SIMPLE PROCESS

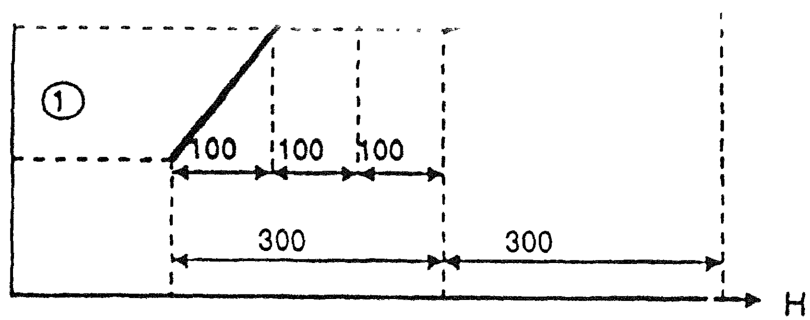


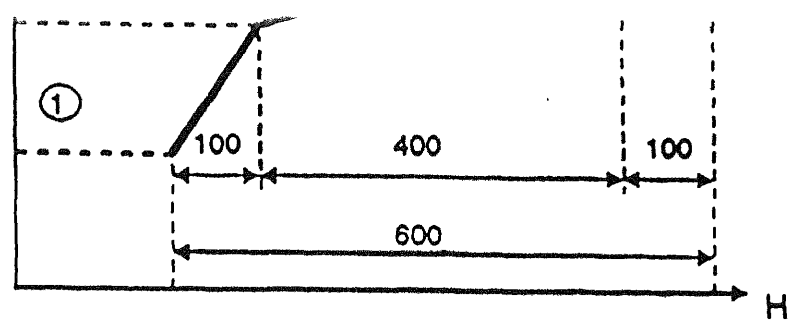


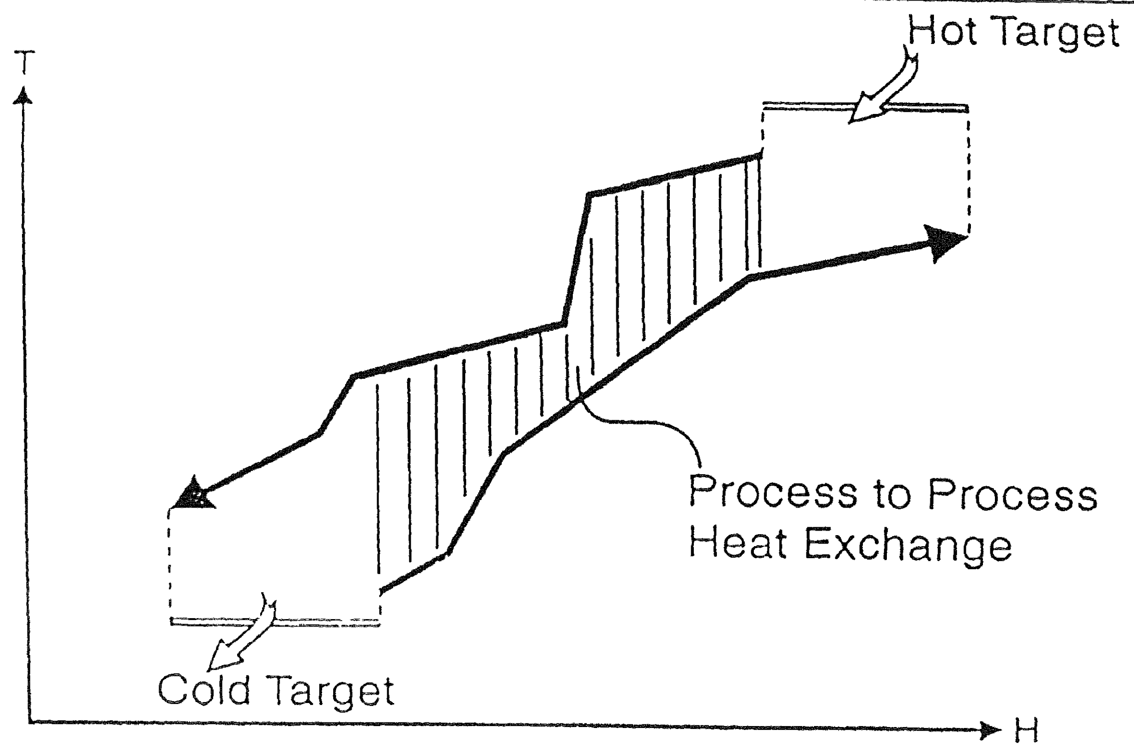
STEAM	=	1722
CW	=	654
AREA	=	629

STEAM	=	1068
CW	=	0
AREA	=	533

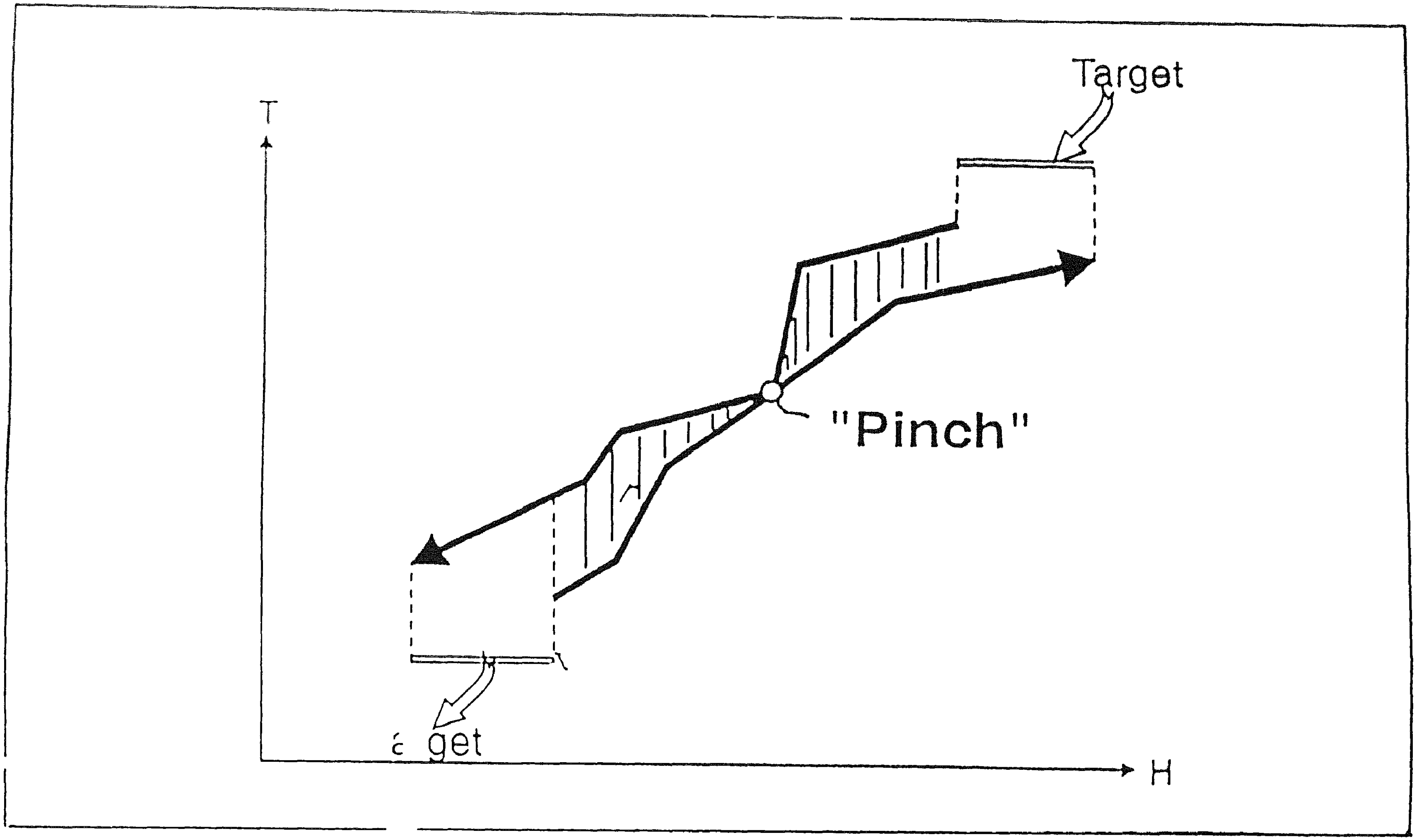
THE CONCEPT OF COMPOSITE CURVE



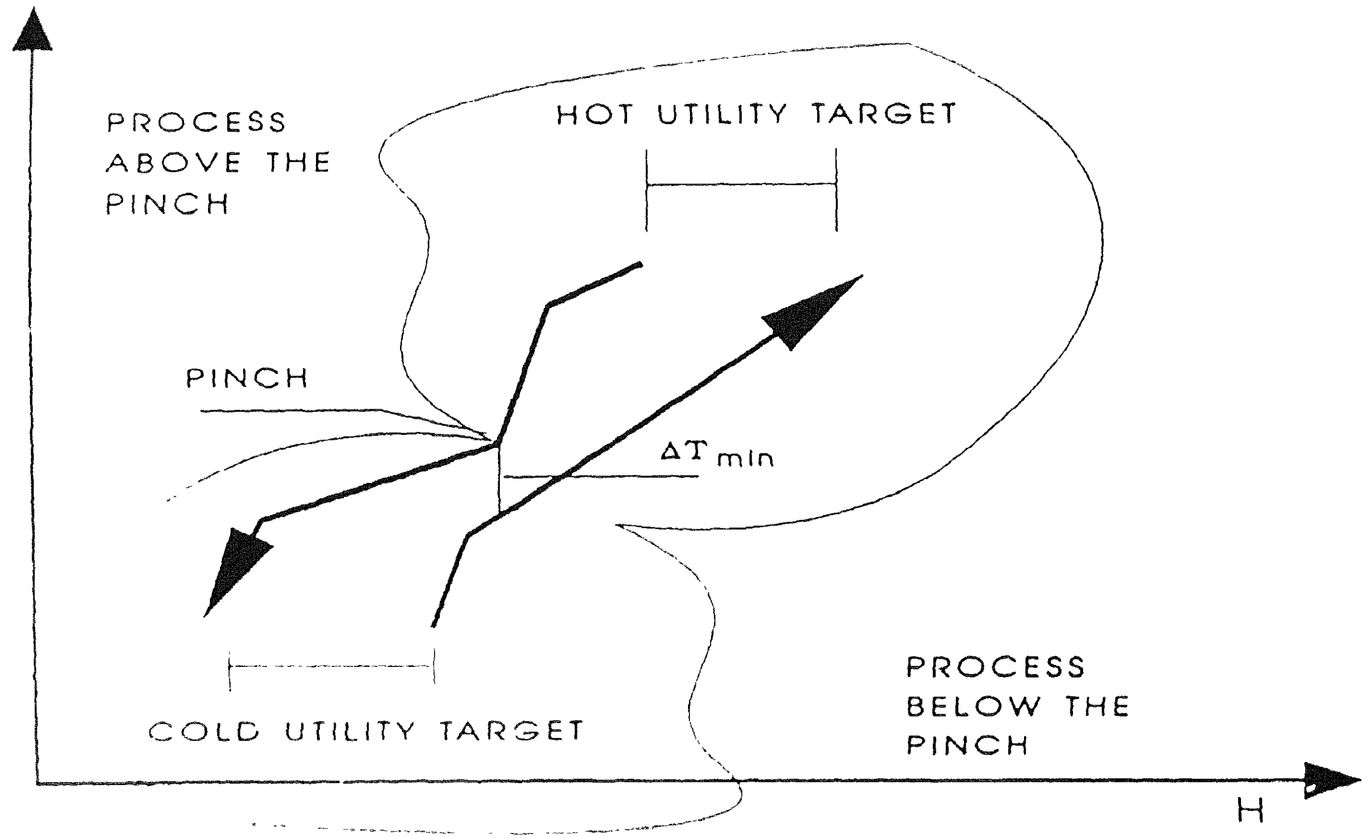




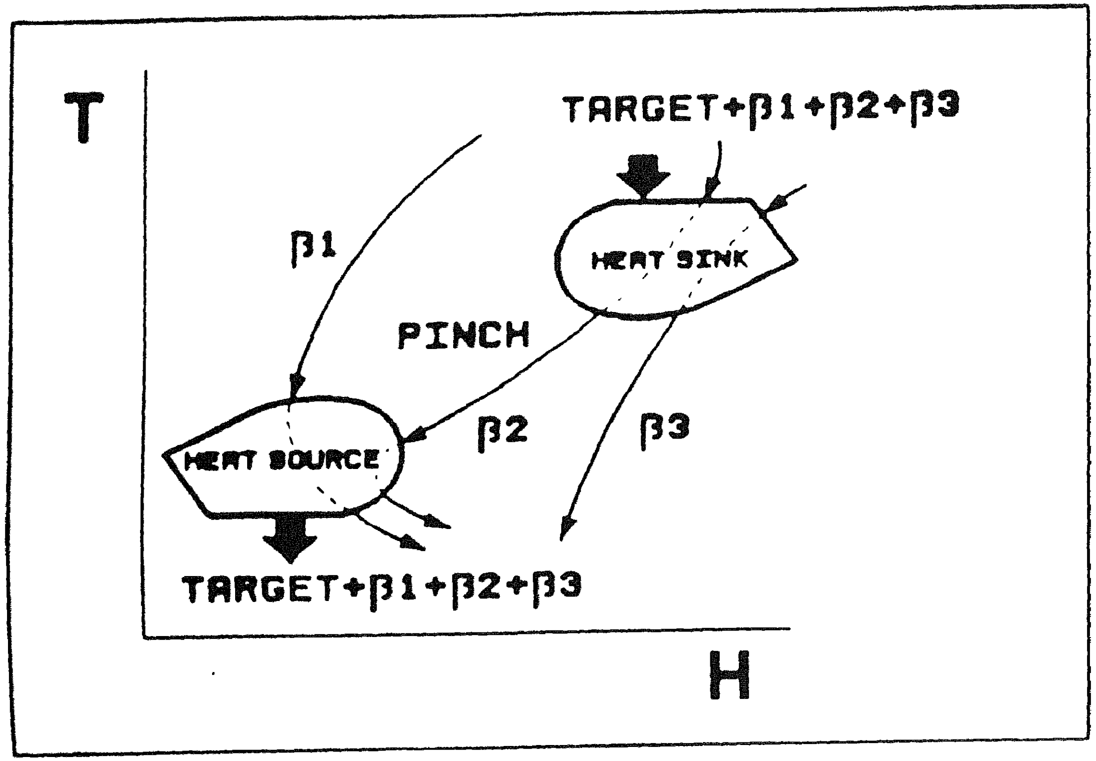
Hot and Cold Composite Curves



A MANNESMANN COMPANY


PROCESS
ABOVE THE
PINCH
HOT UTILITY TARGET
PINCH
ΔT min
COLD UTILITY TARGET
PROCESS
BELOW THE
PINCH
H

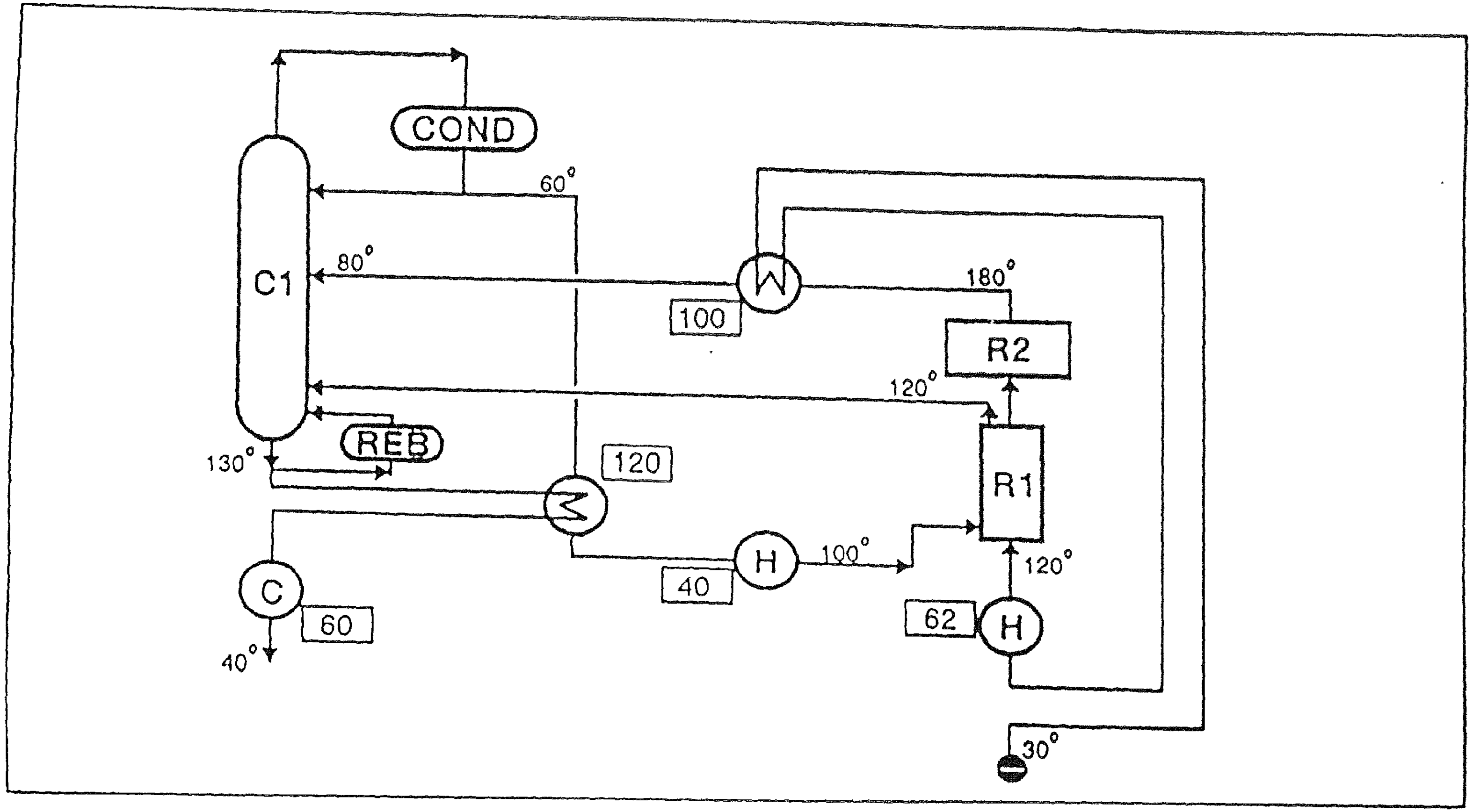
THREE IMPORTANT RULES FOR DESIGN:

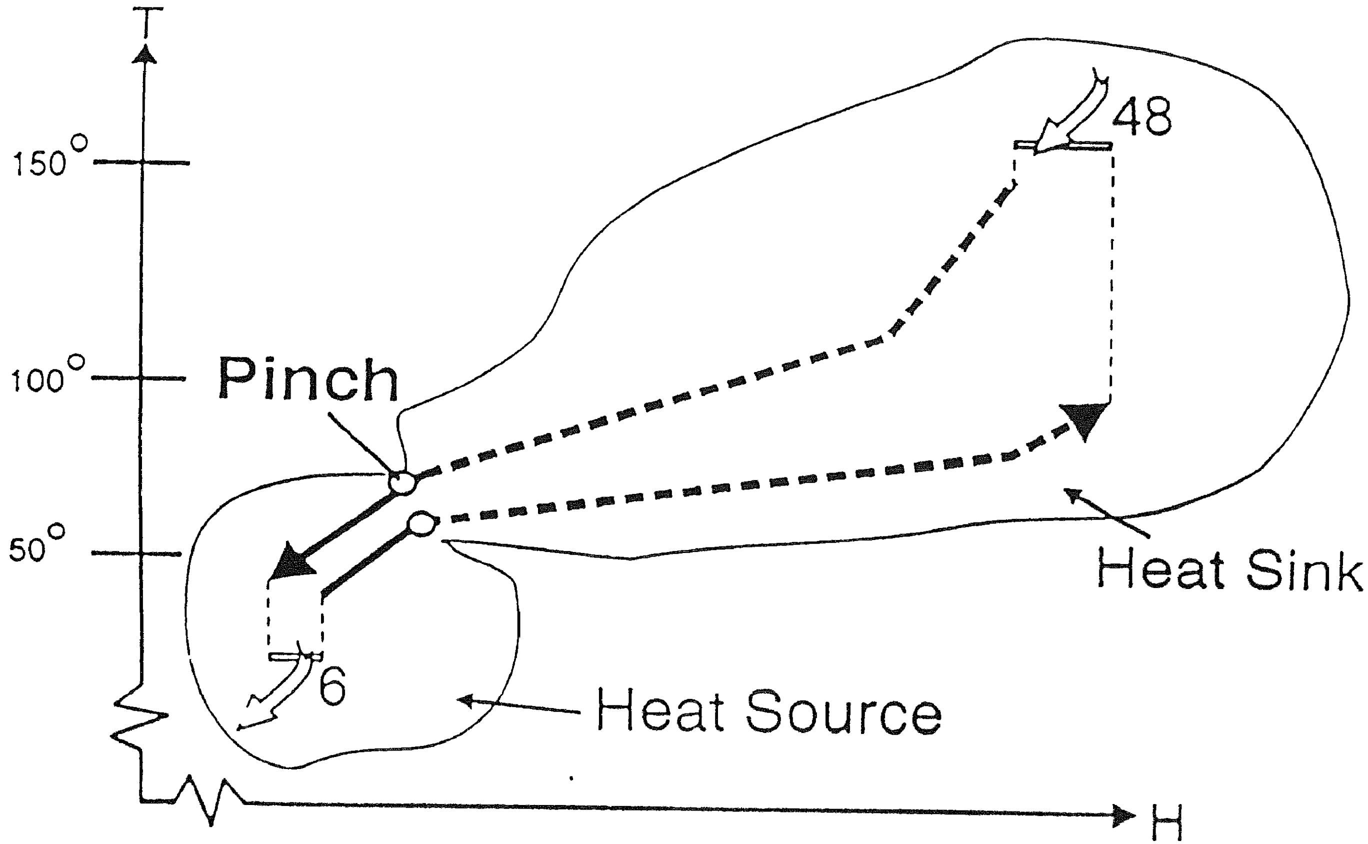


- NO PROCESS HEAT ACROSS ($\beta 2=0$)
- NO COLD UTILITY ABOVE ($\beta 3=0$)
- NO HOT UTILITY BELOW ($\beta 1=0$)

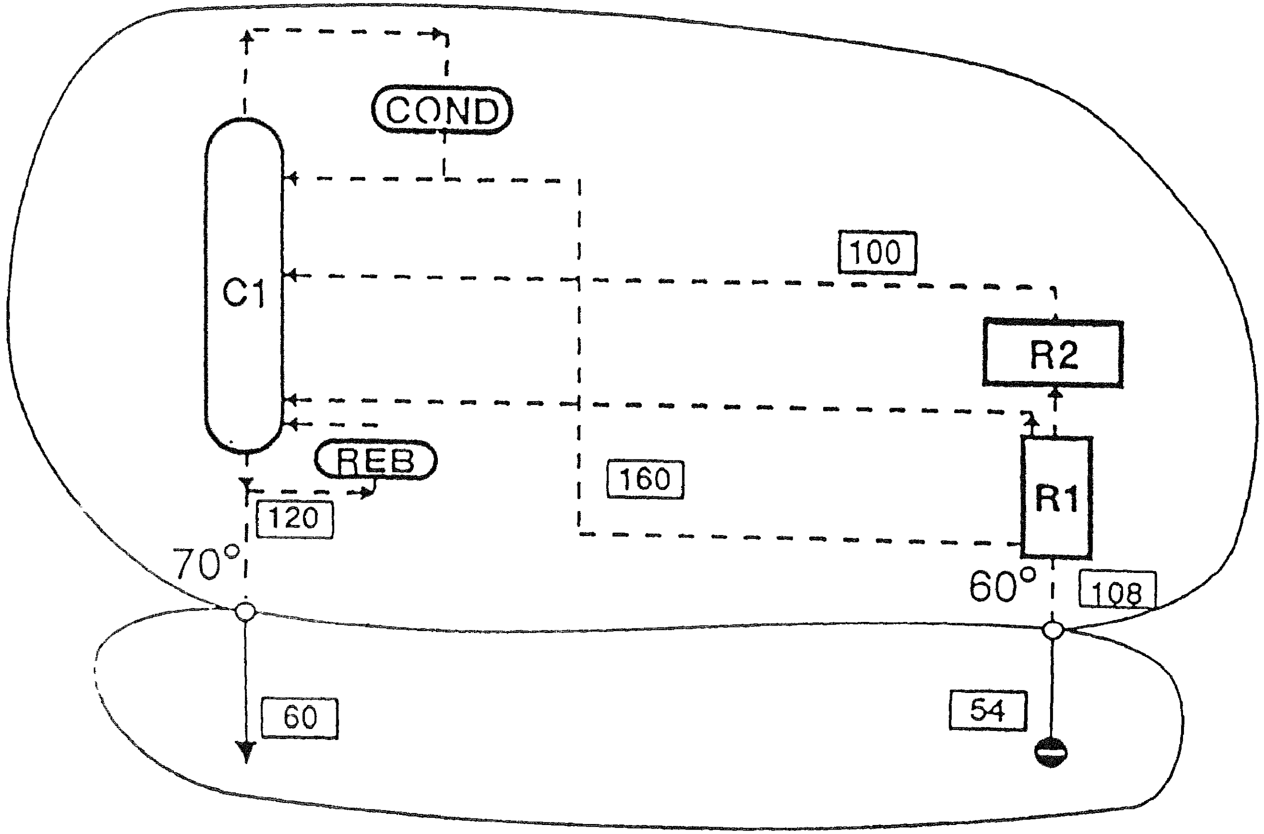
EXAMPLE OF APPLICATION

A MANNESMANN COMPANY


COND
60°
C1
80°
180°
100
R2
120°
REB
130°
120
R1
100°
H
40
120°
C
60
62
H
40°
30°

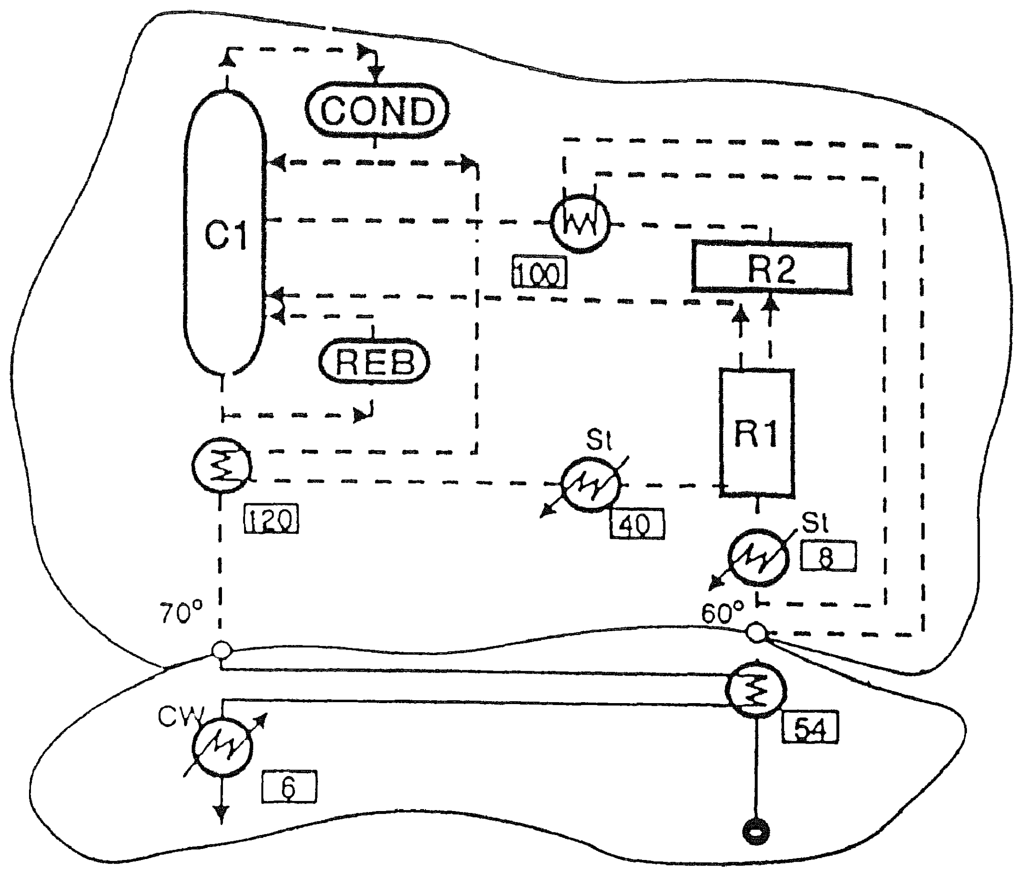


Identify Source and Sink



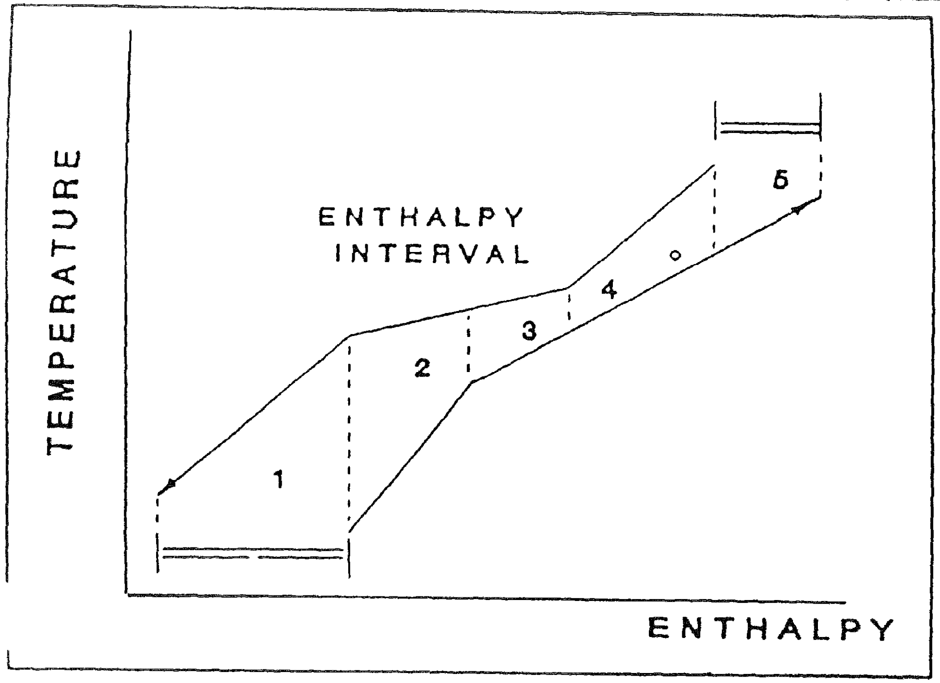
Divide at the Pinch

A MANNESMANN COMPANY



Design in Two parts ⟹ Targets Achieved

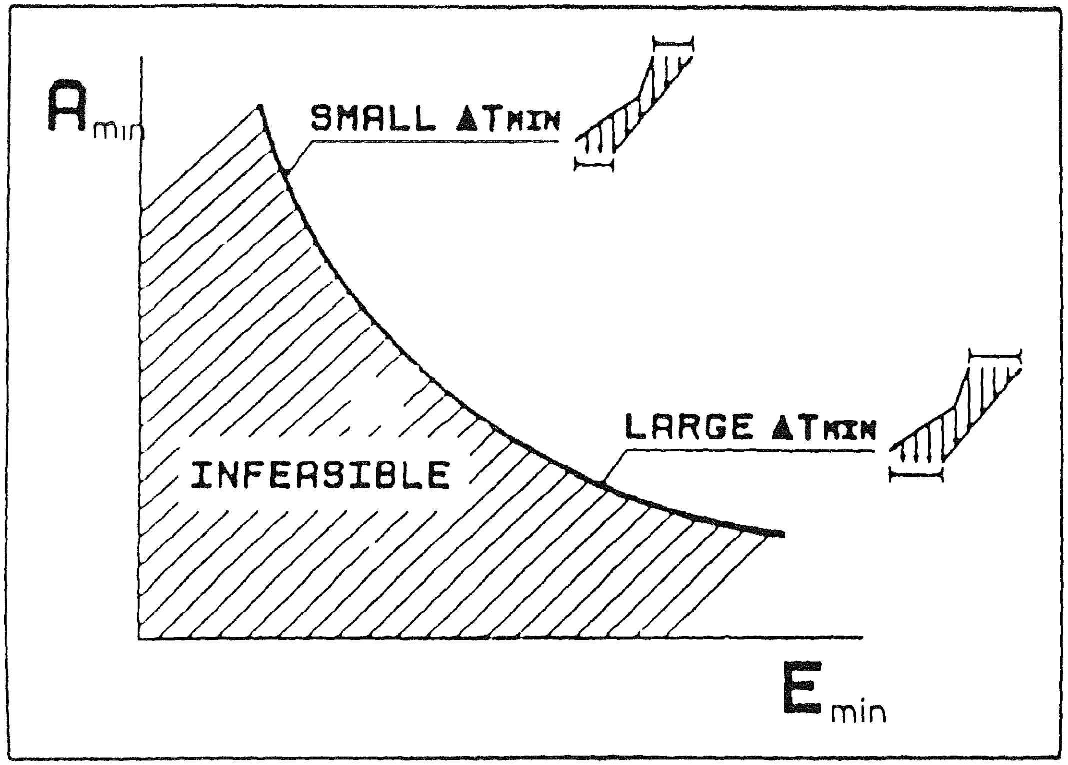
COMPOSITE CURVES... AREA TARGET



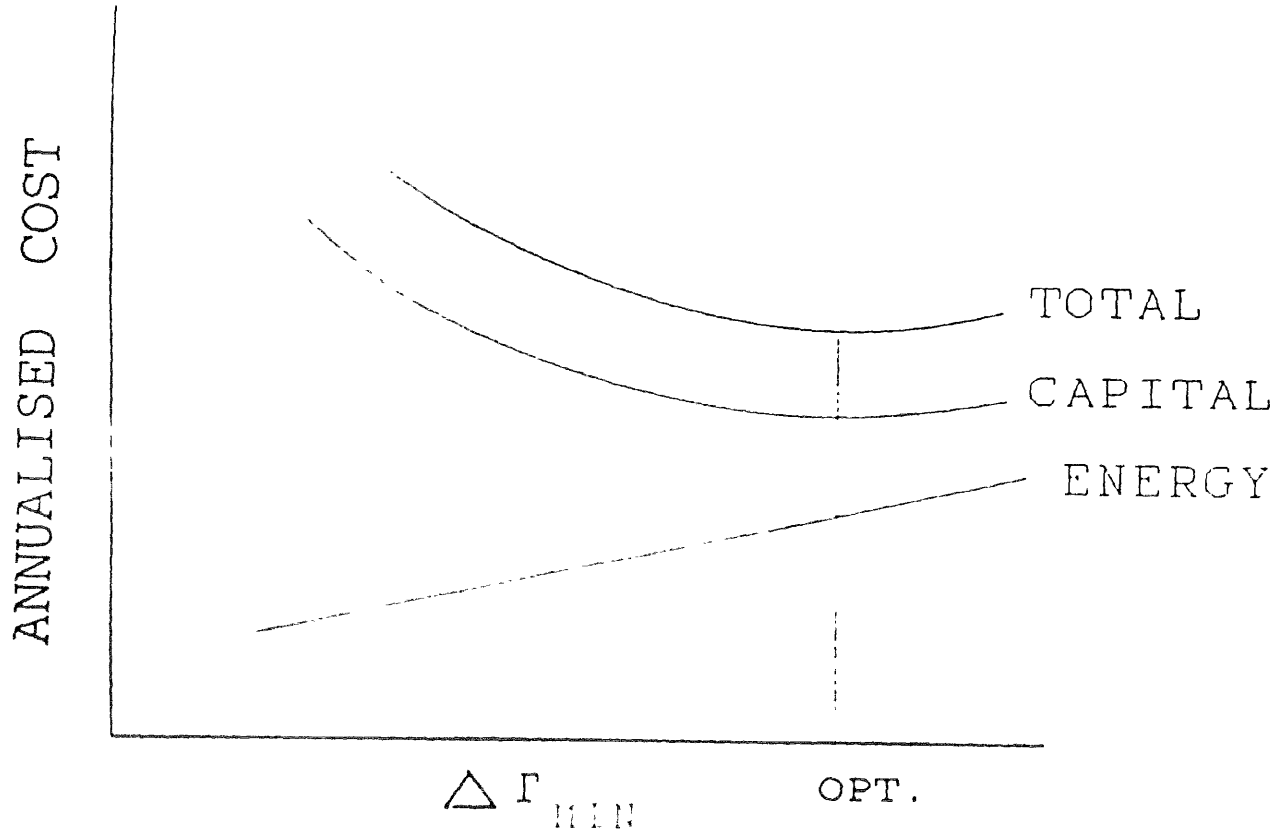
$$A_{min} = \sum_{interval} \frac{1}{\Delta T_{LM}} \sum_{\substack{j \\ streams}} \left(\frac{q_j}{h_j} \right)$$

A MANNESMANN COMPANY

ENERGY AREA PLOT



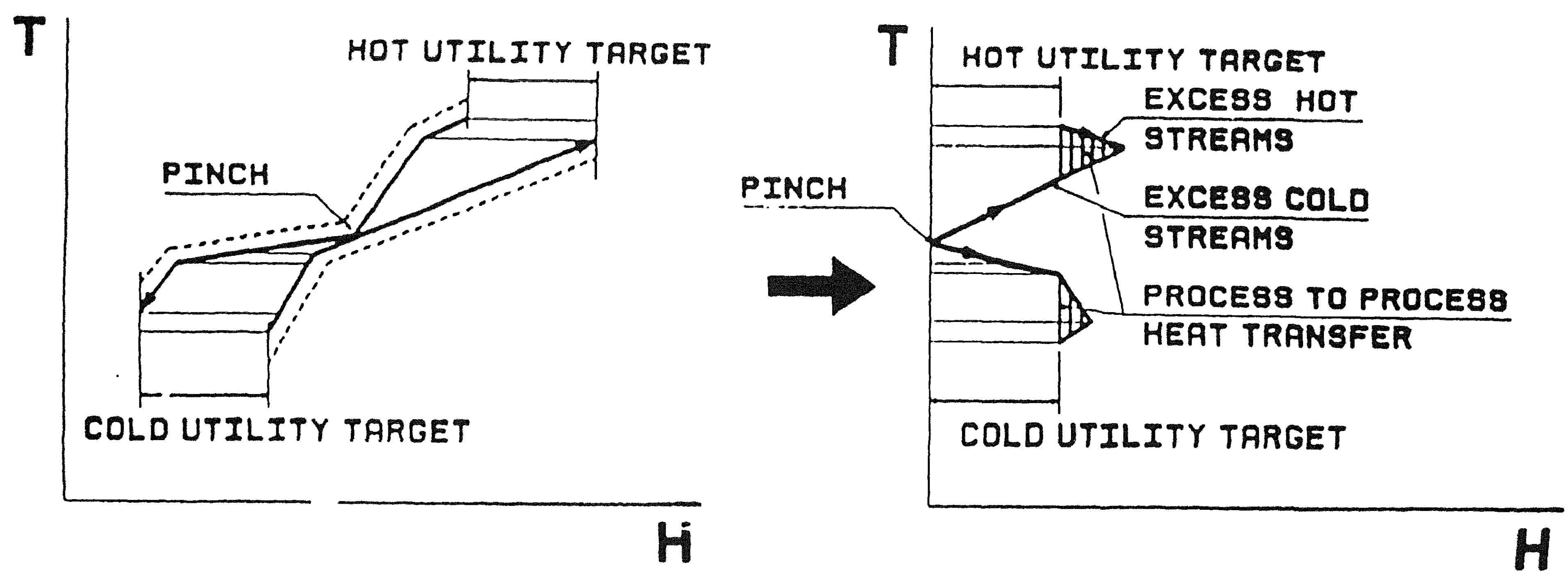
ENERGY / CAPITAL TRADEOFF



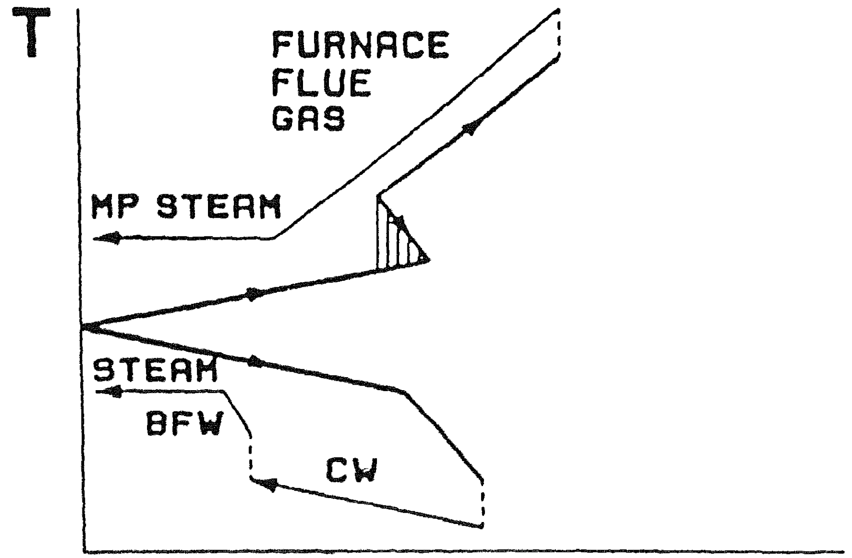
KTI

A MANNESMANN COMPANY

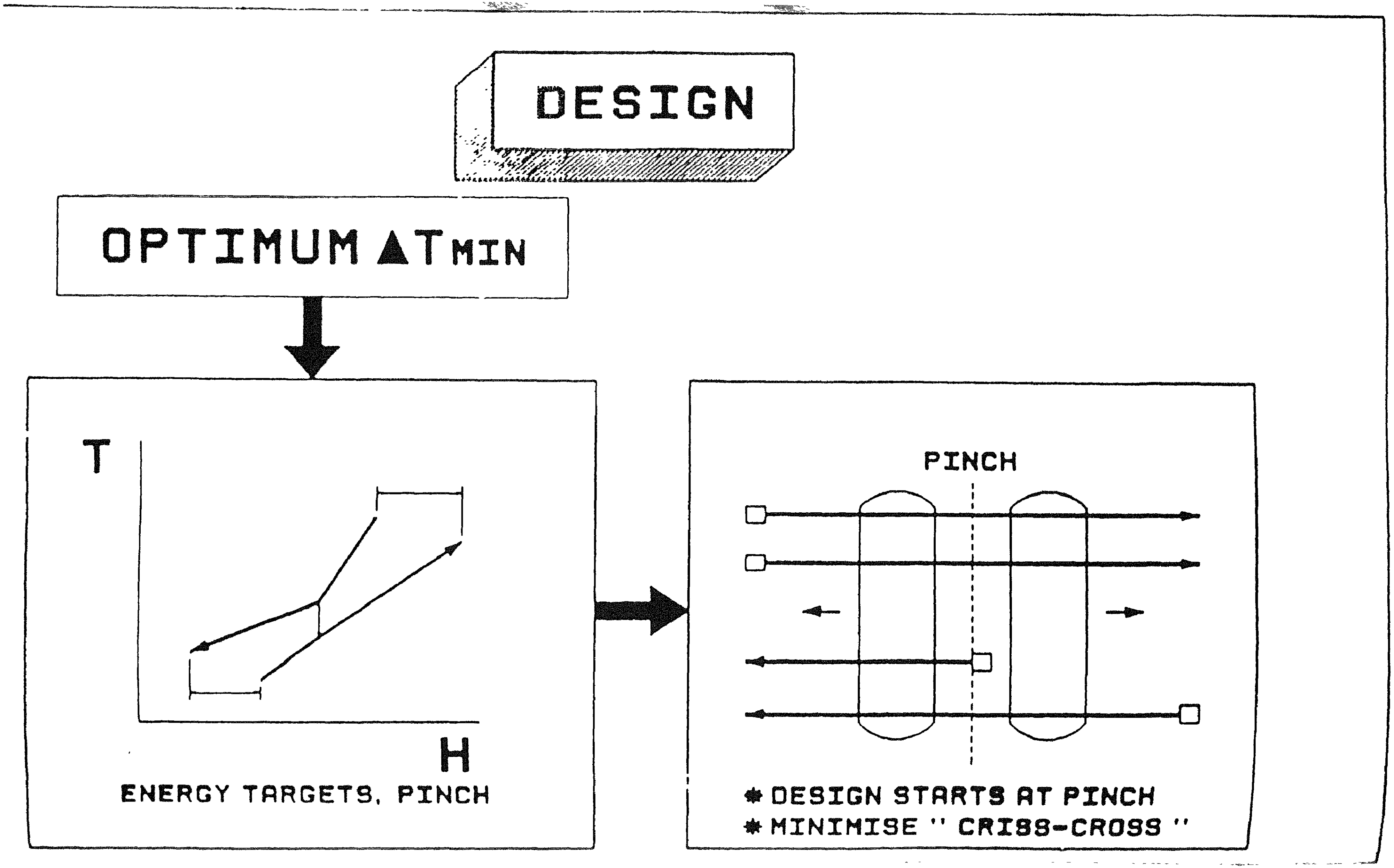
GRAND COMPOSITE CURVE



USE OF GRAND COMPOSITE CURVE



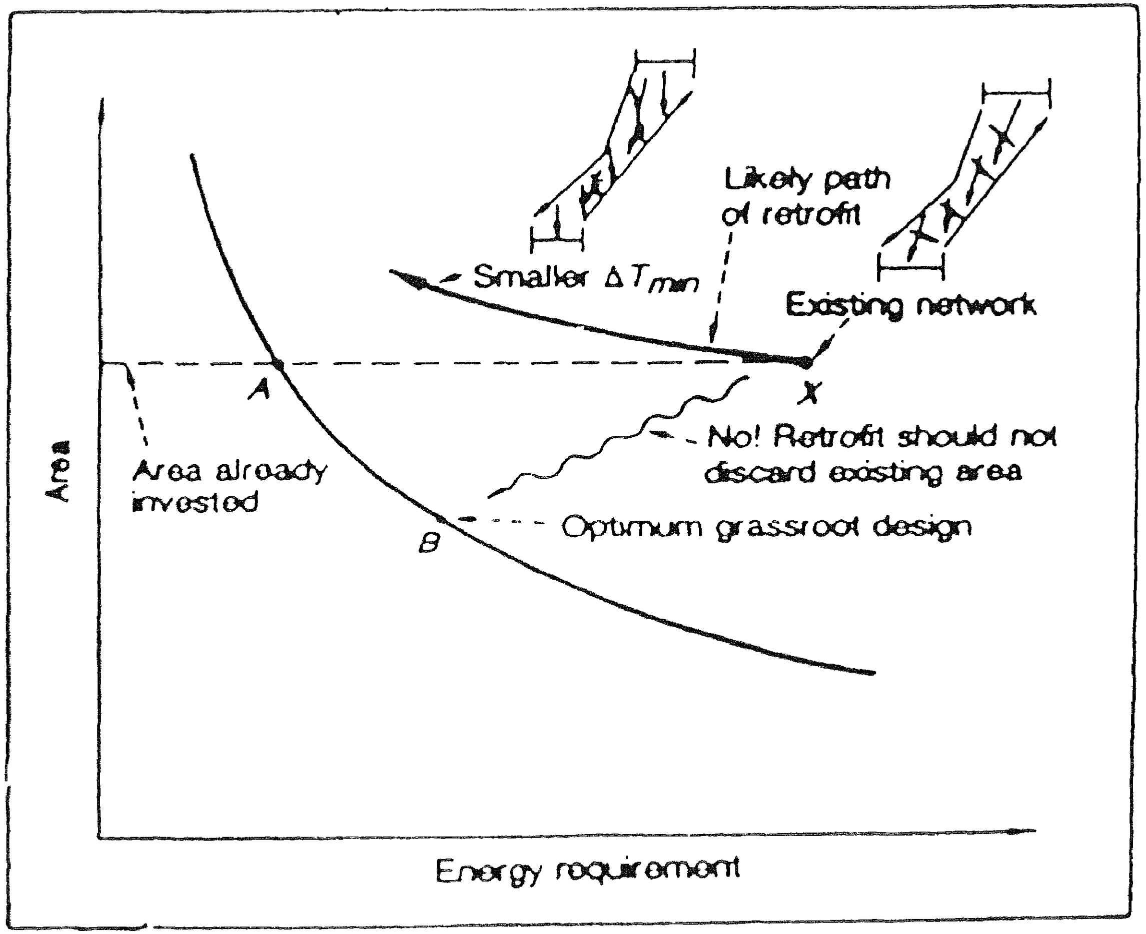
WE CAN SELECT APPROPIATE
UTILITY LEVELS


DESIGN
OPTIMUM ▲T MIN
T
H
ENERGY TARGETS, PINCH
PINCH
* DESIGN STARTS AT PINCH
* MINIMISE " CRISS-CROSS "

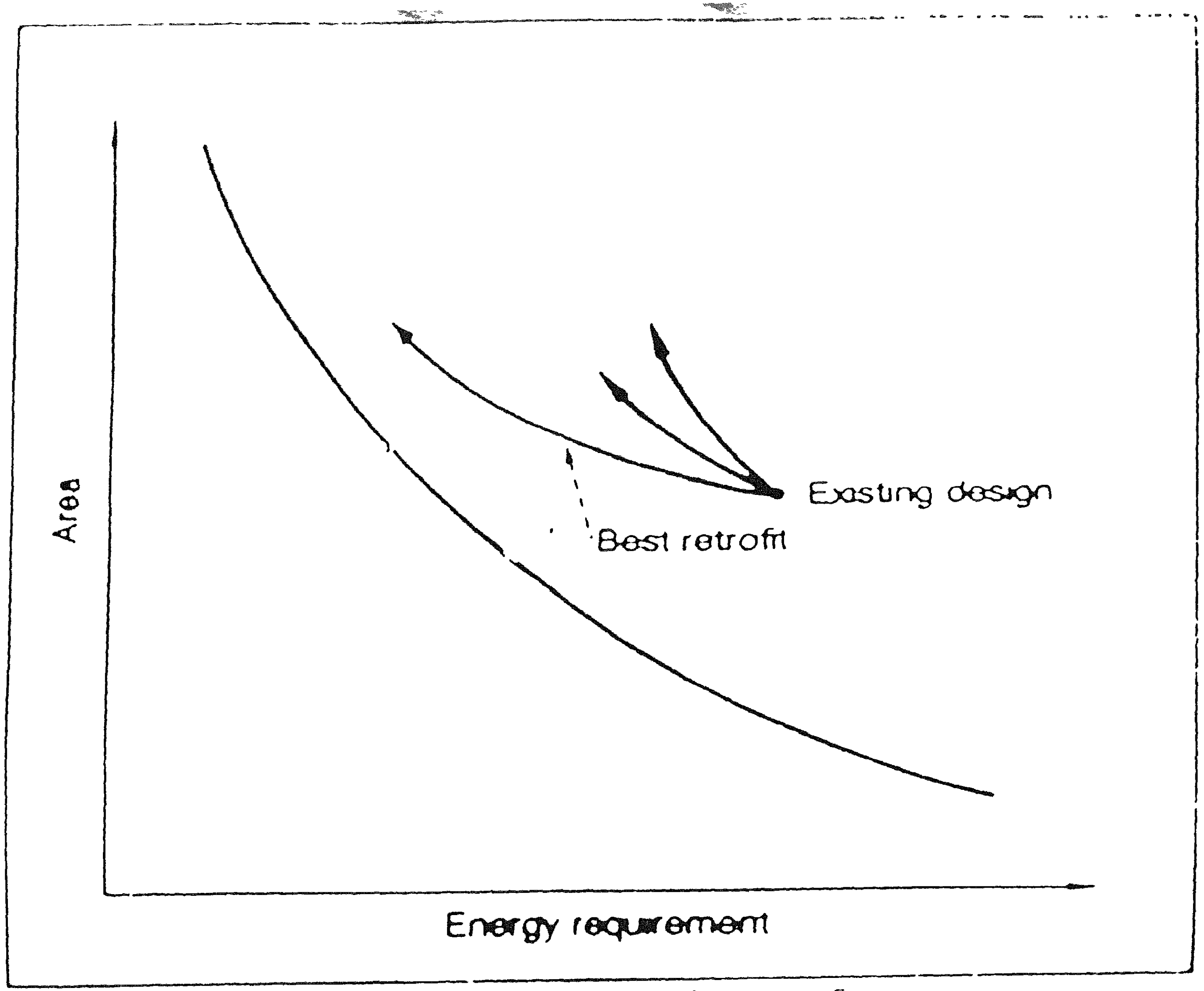
RETROFIT

KTI

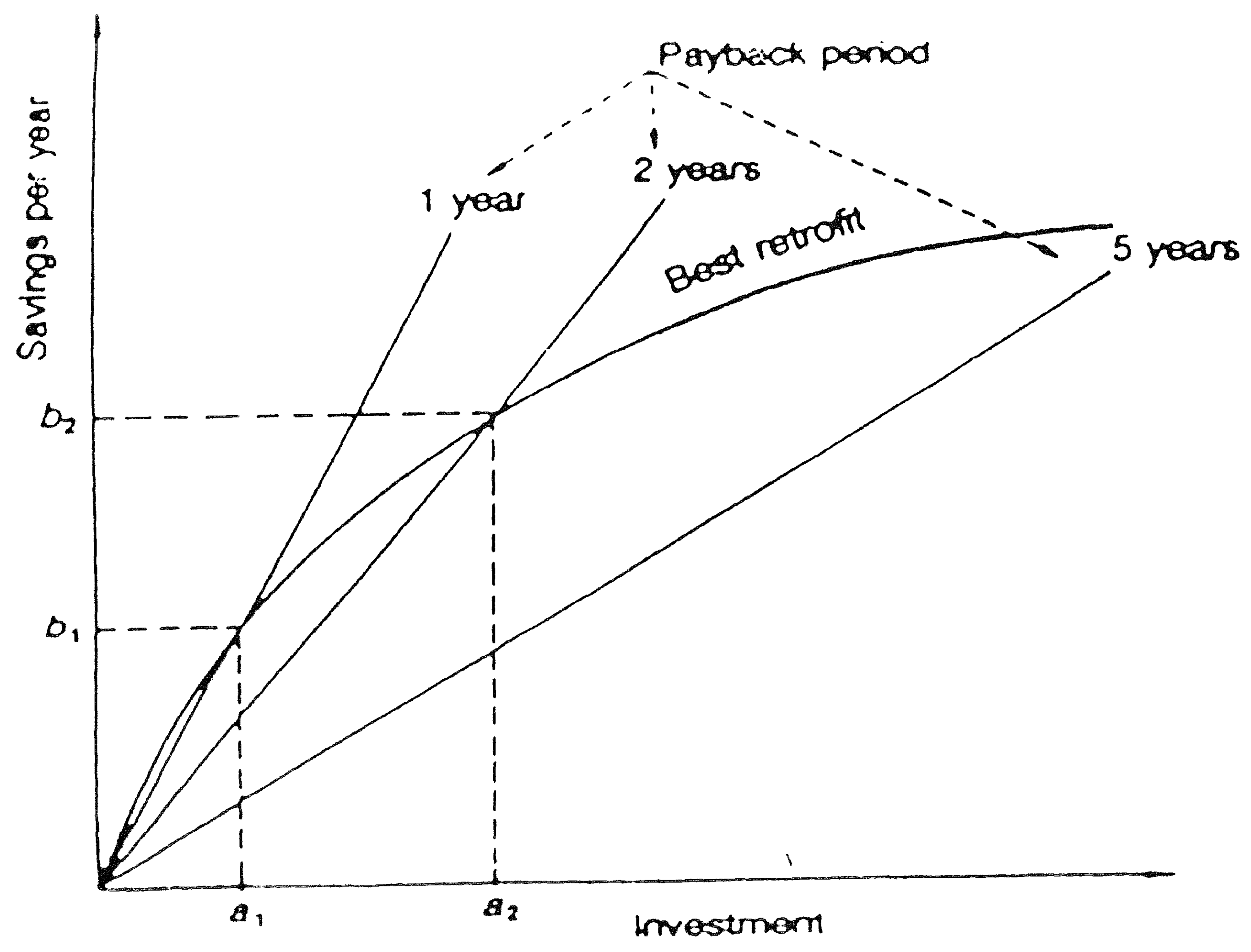
A MANNESMANN COMPANY



A retrofit should try to reach
Point A, not B, to take full advantage of the existing area



Many paths are possible for retrofit,
but bottom curve, whose shape is typical is the best



Best curve for area/energy
can be translated into a savings/investment plot

PINCH TECHNOLOGY : APPLICATIONS IN ...

- REFINERY
- PETROCHEMICALS
- FERTILIZERS
- SPECIALITY CHEMICALS
- BREWERY
- FOOD PROCESSING
- PULP AND PAPER
- CEMENT
- TEXTILES
- SUGAR

KTI

A MANNESMANN COMPANY

PETROCHEMICALS

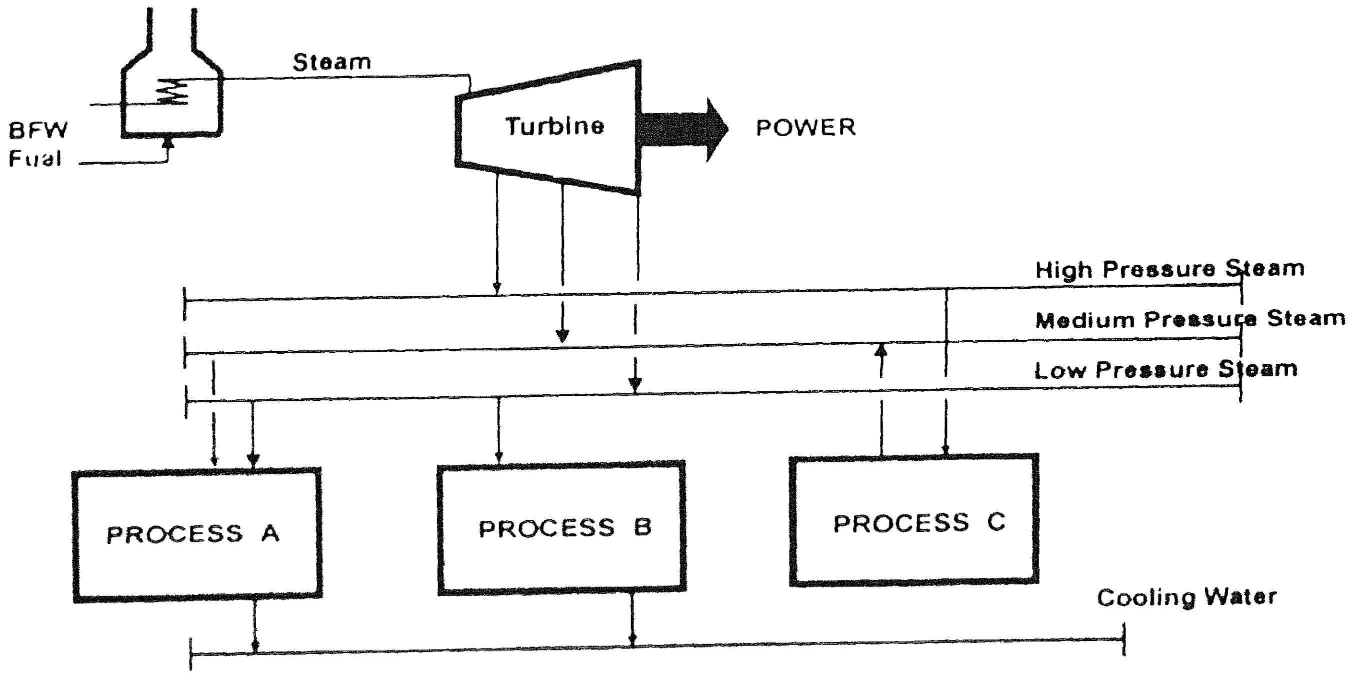
ACETIC ACID
AMINES
AROMATICS
BTX
BUTADIENE
CAPROLACTUM
CYCLOHEXANE
ETHYLENE
PHENOL
PTHALIC ANHYDRIDE
POLYMERS
STYRENE
VINYL CHLORIDE MONOMER

BULK INORGANICS

AMMONIA
CHLOR - ALKALI
FERTILISERS
GENERAL CHEMICALS
NITRIC ACID
SODA ASH
SULPHURIC ACID
UREA

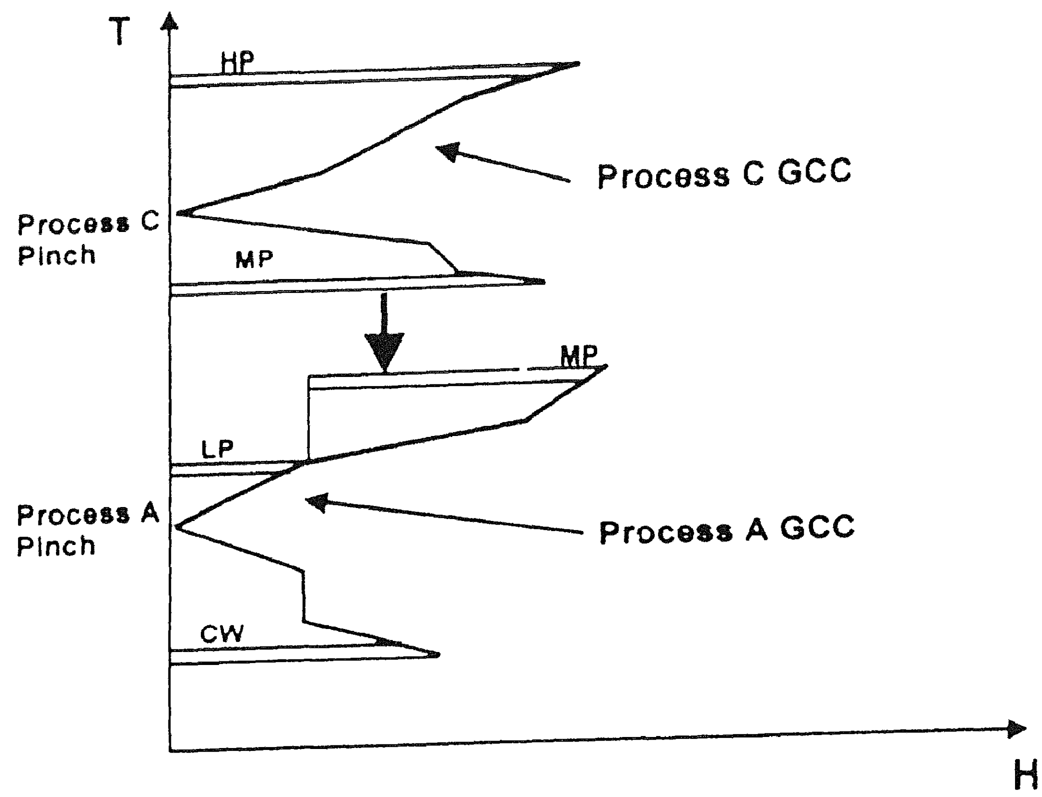
TOTAL

SITE

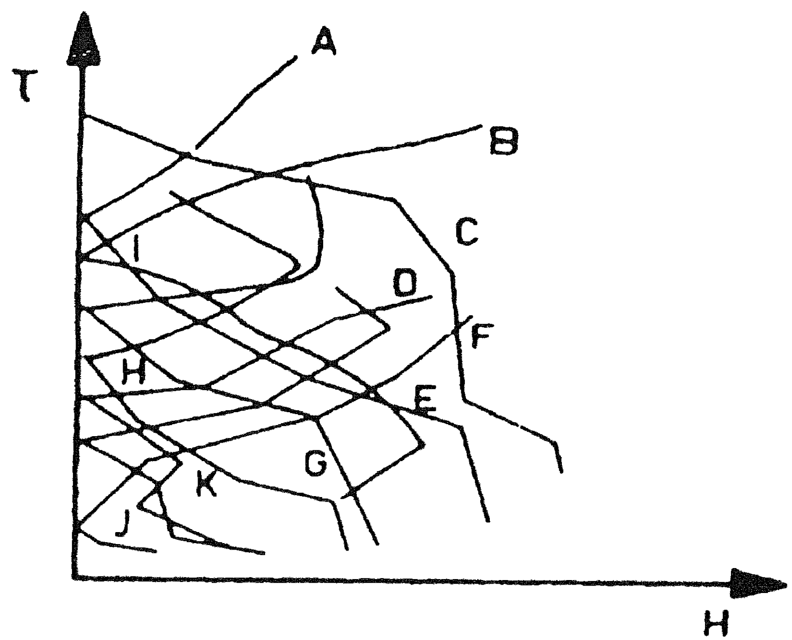


Steam
BFW
Fuel
Turbine
POWER
High Pressure Steam
Medium Pressure Steam
Low Pressure Steam
PROCESS A
PROCESS B
PROCESS C
Cooling Water

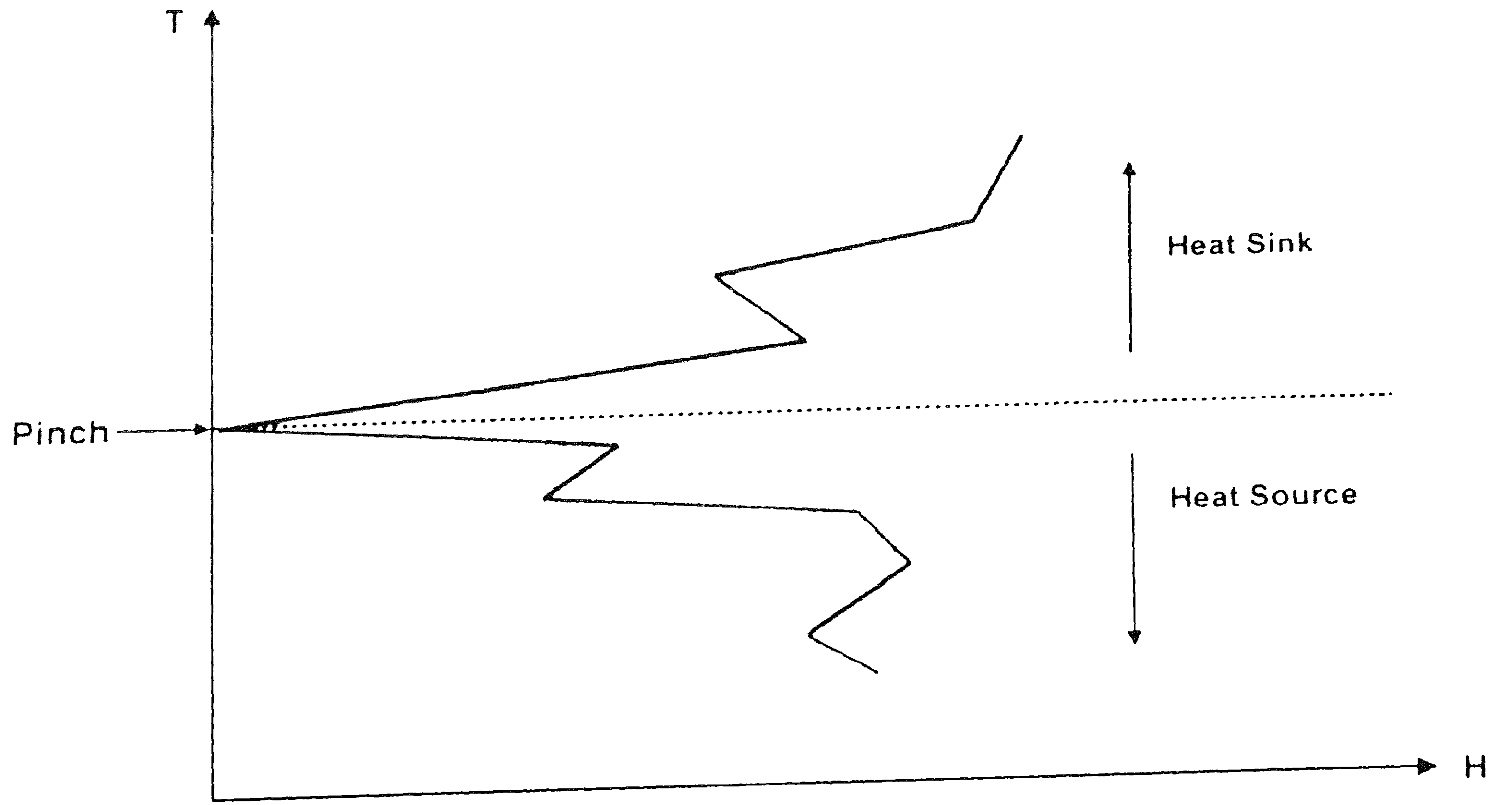
A Total Site



Integration Between Processes

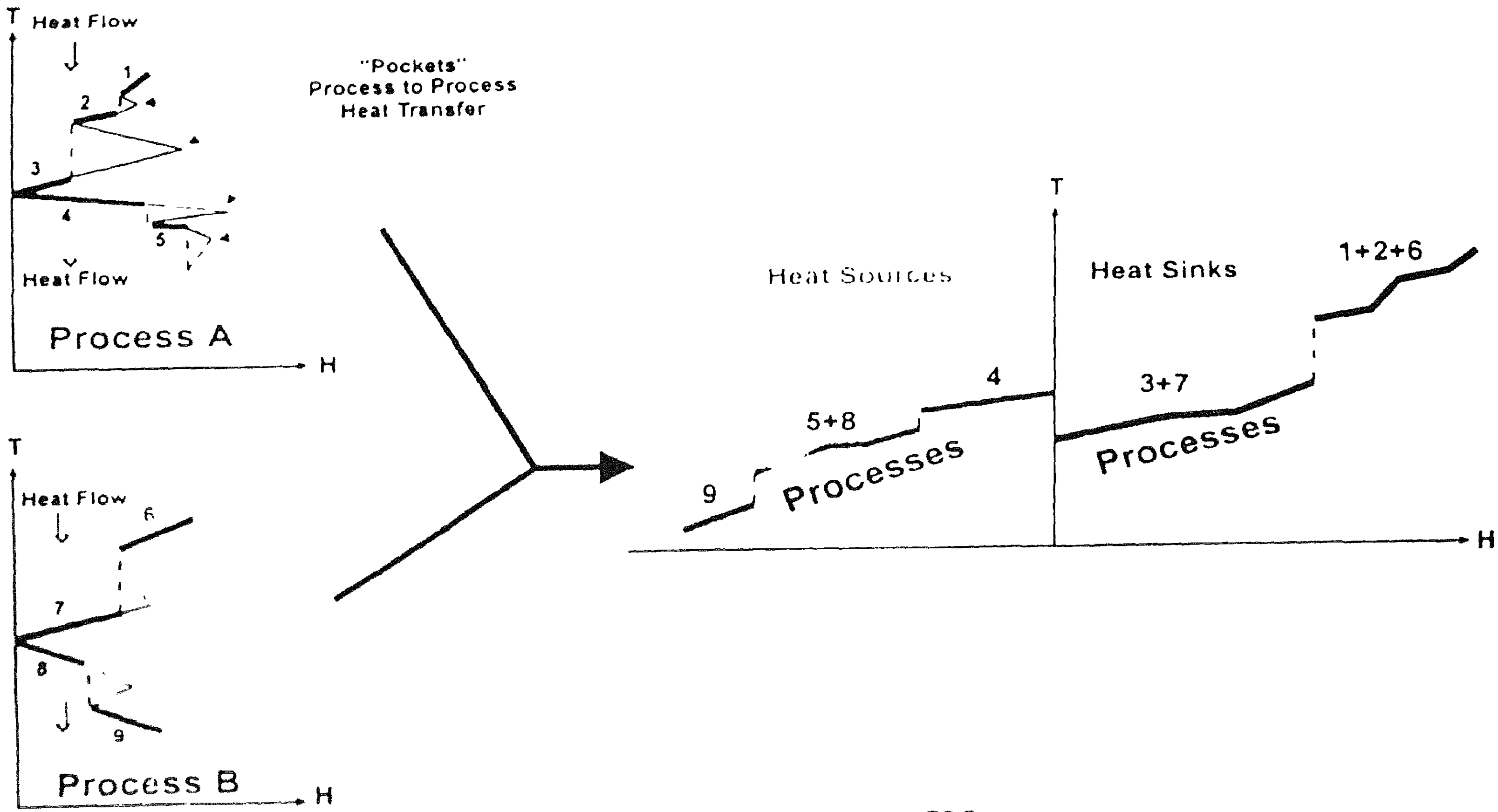


An Example of Several Processes



Heat Sink and Heat Source on the Grand Composite Curve

PT-27

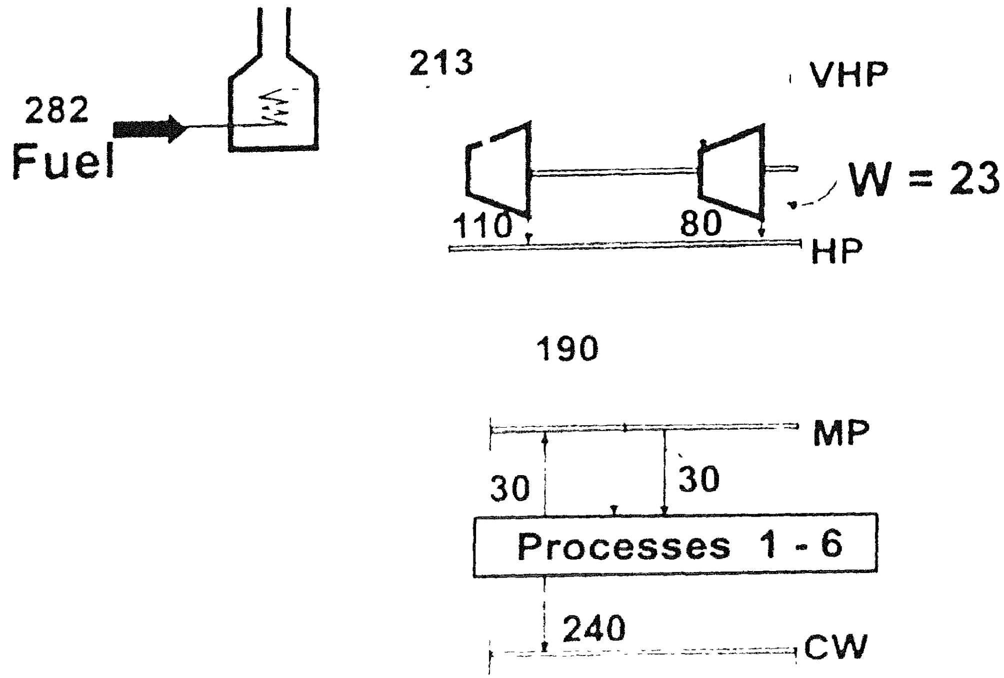


Total Site Profiles

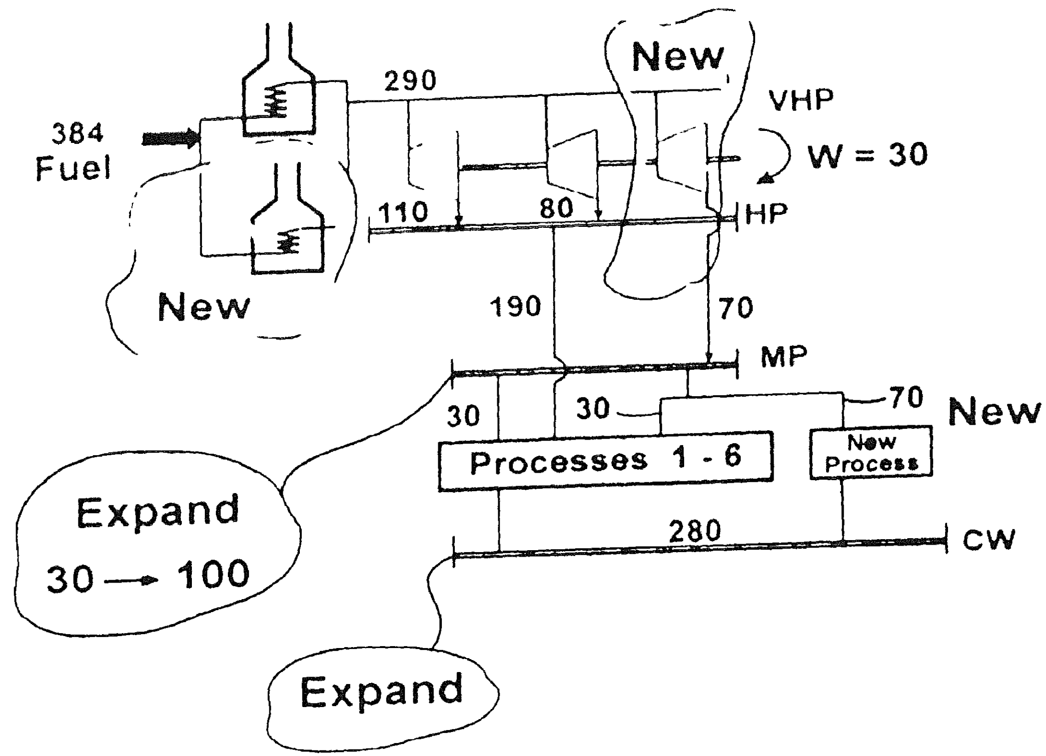
PT-28

Example

Existing

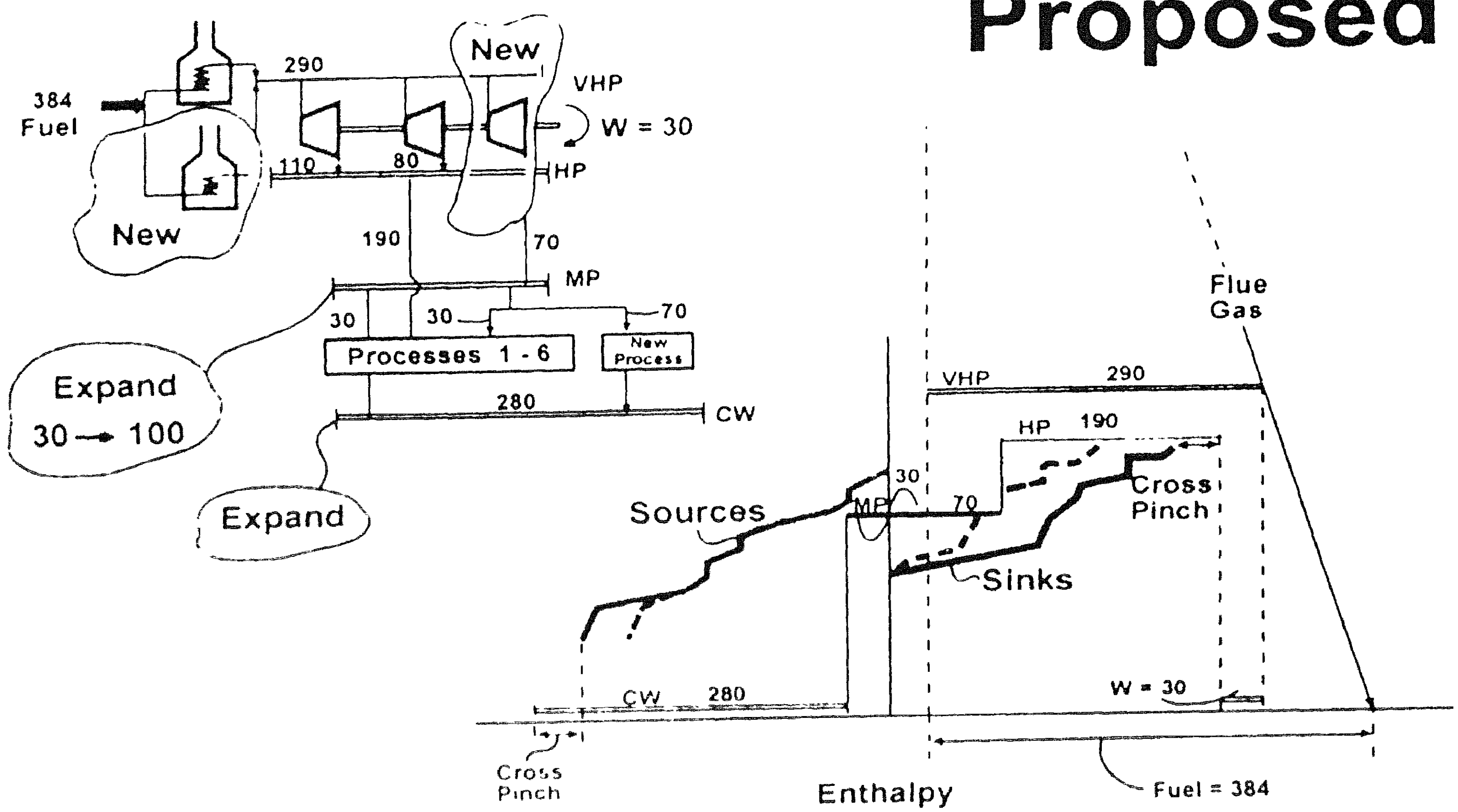


Proposed



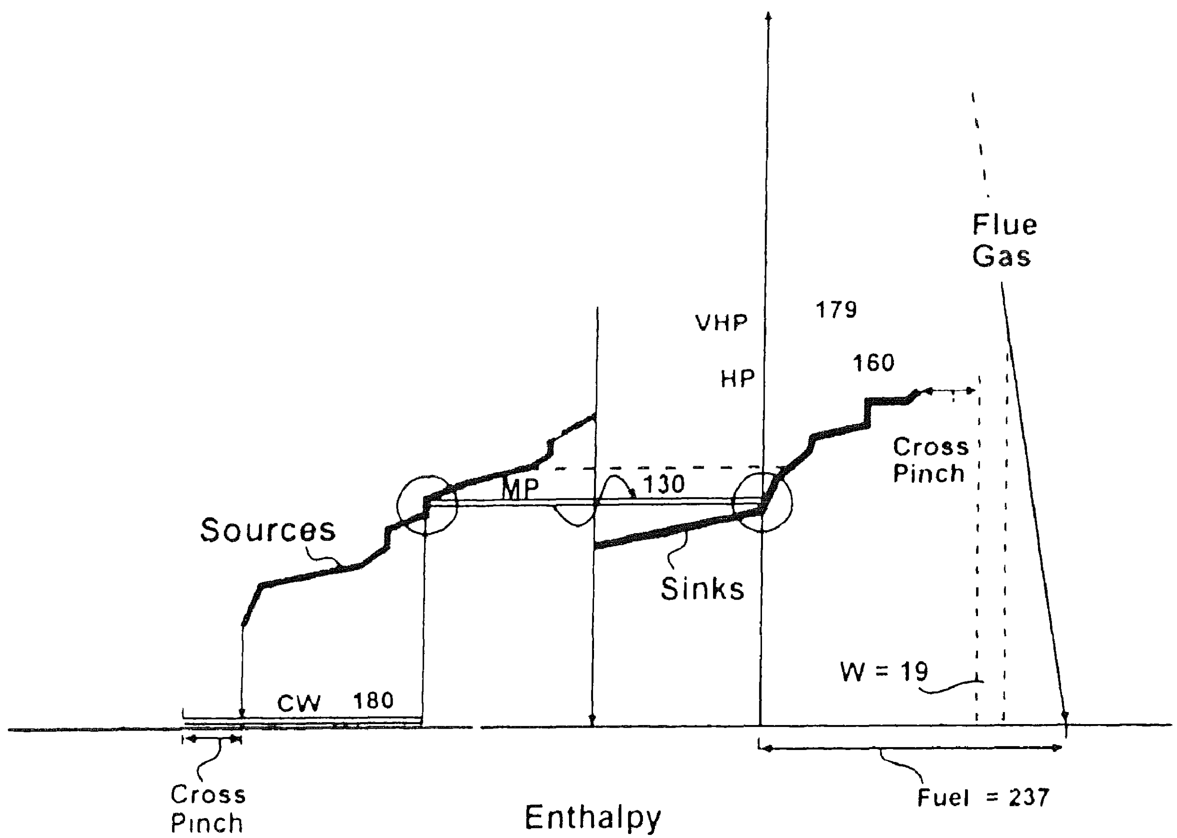
PT-31

Proposed

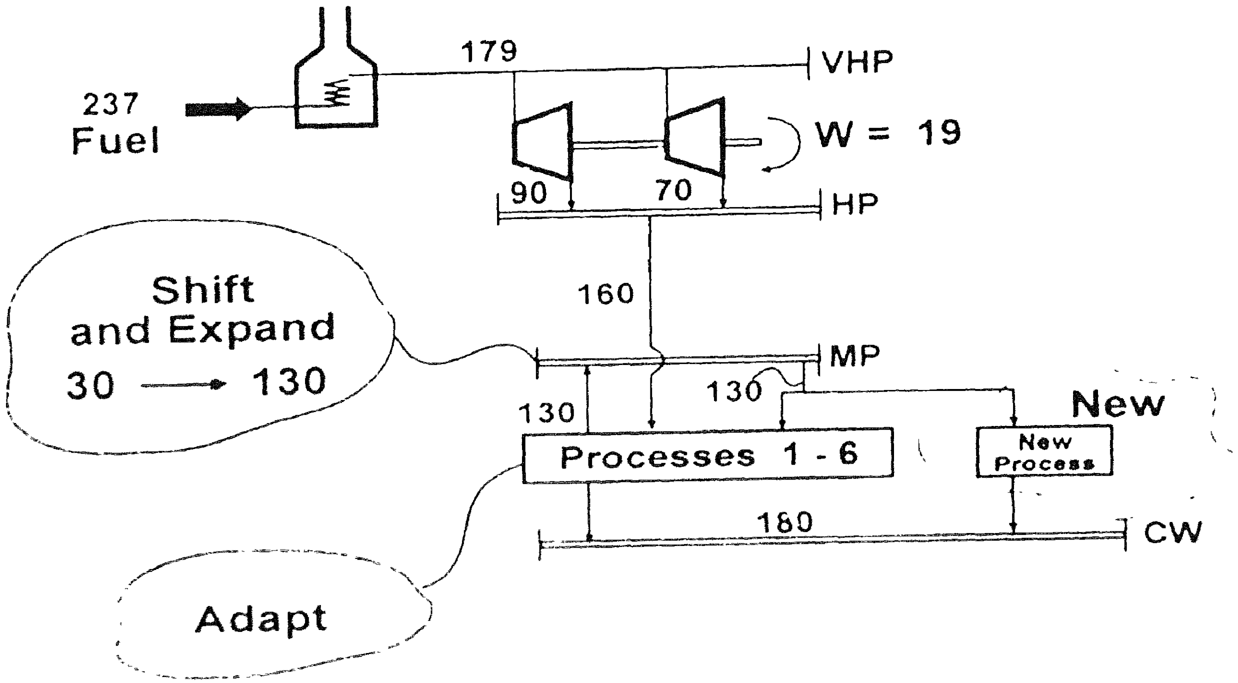


PT-32

Alternative



Alternative



PT-34

	Proposed	Alternative
CO_2 (Global)	100%	86%
Total Utilities Operating Cost	100%	81%
Capital Cost Implications	• Expand MP • New Turbine • New Boiler • Expand Cooling	• Shift MP Pressure & Expand • Adapt Processes to Suit

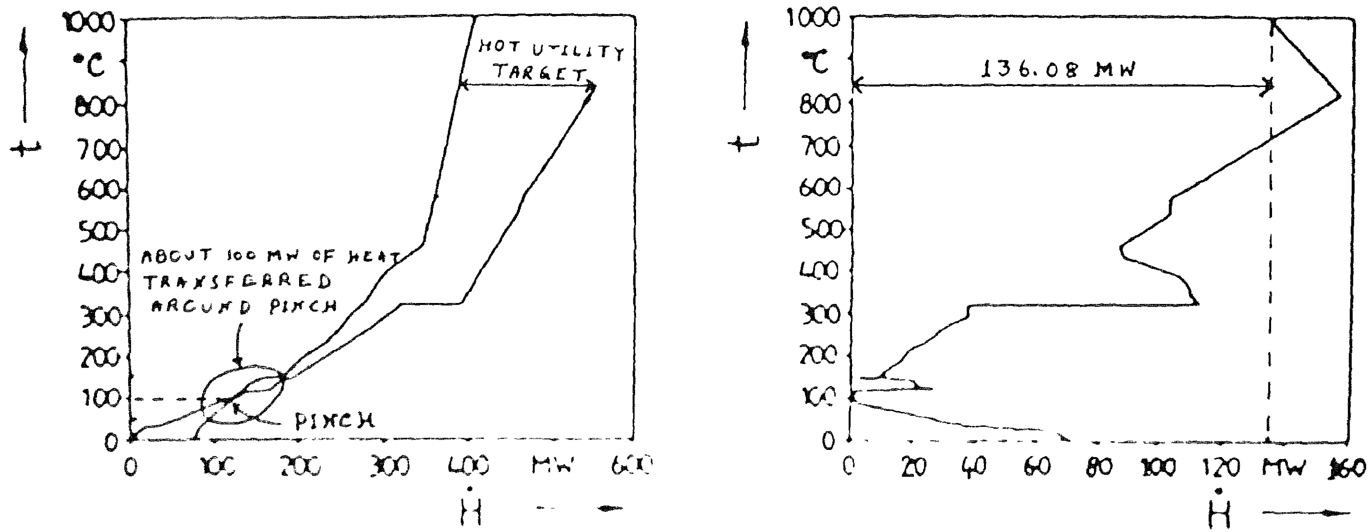
APPLICATION TO FERTILIZER COMPLEXES

- AMMONIA AND UREA PLANTS
- HEAT INTEGRATION WITH NITRIC ACID PLANT - AN EXAMPLE
- PHOSPHORIC ACID PLANT
- EVAPORATOR PLANT

APPLICATION OF PINCH ANALYSIS IN AMMONIA/UREA COMPLEX

KTI

A MANNESMANN COMPANY



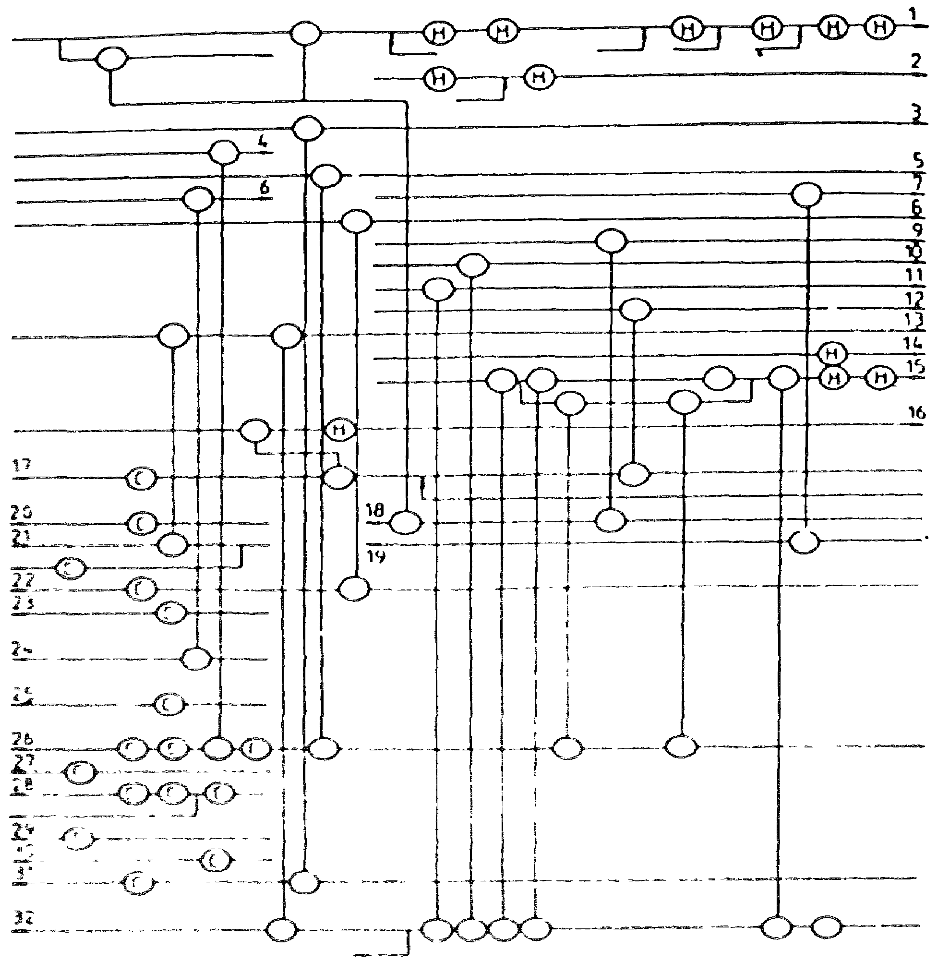
Composite curves and grand composite curve of the ammonia plant

<u>OBSERVATIONS</u>

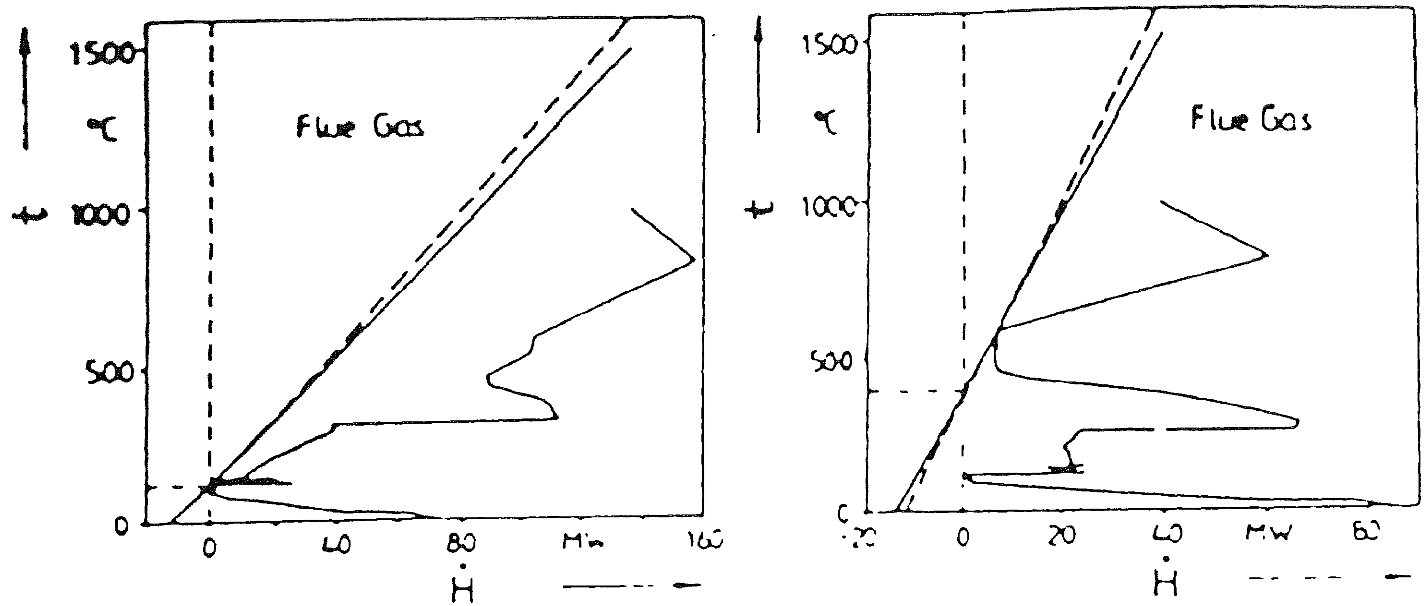
- TYPICAL ENERGY SAVING POTENTIAL - 8%
- WAY FORWARD

1) TO IDENTIFY PINCH RULE VIOLATORS AMONG THE PRESENT HEAT EXCHANGERS

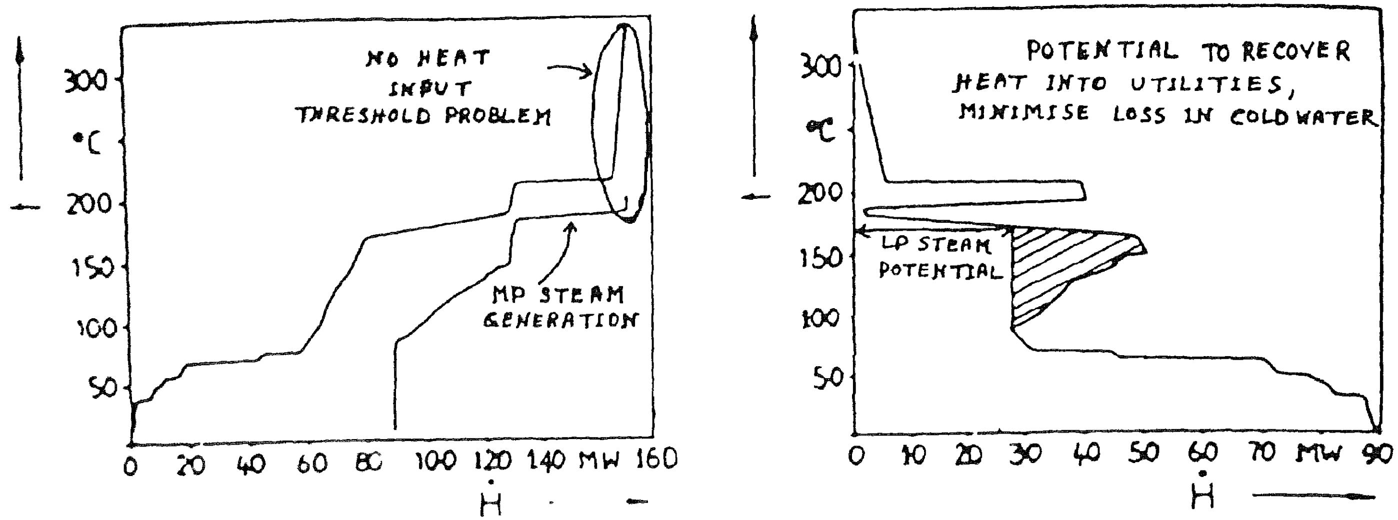
2) ABSORPTION OF AVAILABLE HEAT INTO UTILITIES



Heat exchanger network of ammonia plant



Elimination of flue gas losses by high pressure steam production

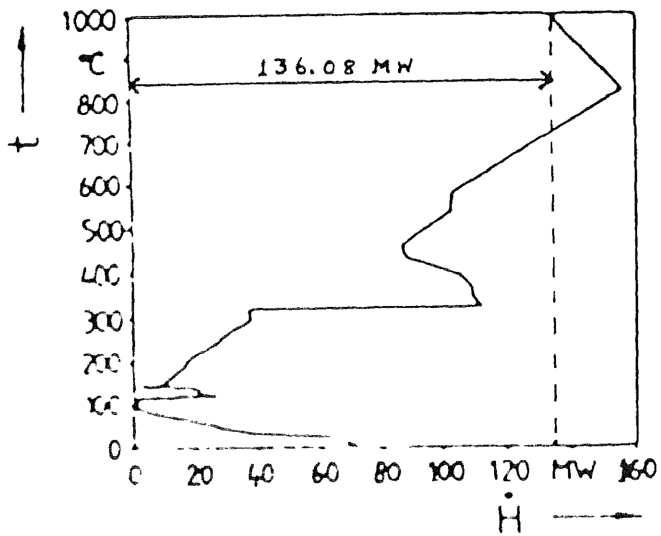


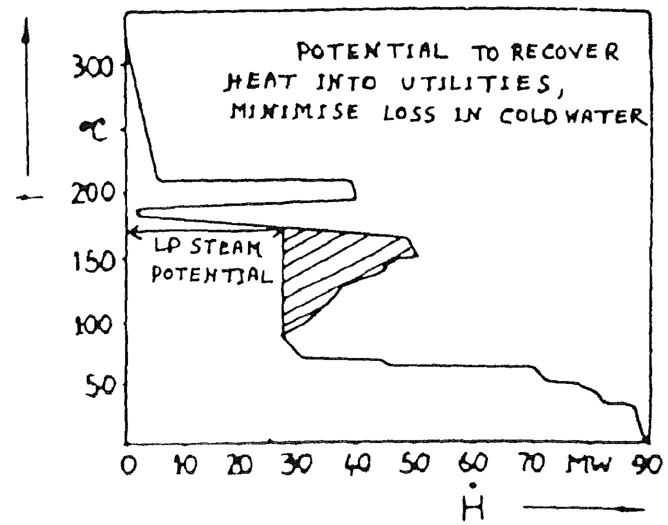
Composite curves and grand composite curve of the urea plant

CONCLUSION

- AMMONIA PLANT IS IN NET HEAT DEFICIT
- UREA PLANT IS IN NET HEAT SURPLUS

PERHAPS IT MIGHT BE POSSIBLE TO HEAT INTEGRATE THE TWO





GRAND COMPOSITE CURVES OF AMMONIA AND UREA PLANT

A MANNESMANN COMPANY

HEAT INTEGRATION BETWEEN AMMONIA AND UREA PLANTS

▪ TOTAL ENERGY SAVING POTENTIAL	19 MW
▪ PRACTICAL POTENTIAL WITHIN REASONABLE PAYBACK	15 MW
1. MODIFICATION IN AMMONIA PLANT	11 MW
2. INCREASED LP STEAM IN UREA PLANT	4 MW

AMMONIA AND UREA PLANT SUMMARY

- AMMONIA PLANT PINCH TEMPERATURE IS TYPICALLY AROUND 100 ^{o}C
- POTENTIAL TO SAVE ENERGY BY 8%
- HEAT EXCHANGER NETWORK OPERATES AT LOW TEMPERATURE DRIVING FORCE AROUND PINCH, HOWEVER 100 MW OF ENERGY IS TRANSFERRED BETWEEN 50-150 ^{o}C
- BENEFICIAL TO GENERATE HP STEAM RATHER THAN PROCESS TO PROCESS EXCHANGE

- UREA PLANT IS A THRESHOLD CASE WITH POTENTIAL TO GENERATE LP STEAM
- UREA PLANTS SHOULD BE OPTIMISED TO MINIMISE LOSSES INTO COLD WATER
- HEAT INTEGRATION OF AMMONIA AND UREA PLANTS CAN LEAD TO 15 MW OF ENERGY SAVINGS

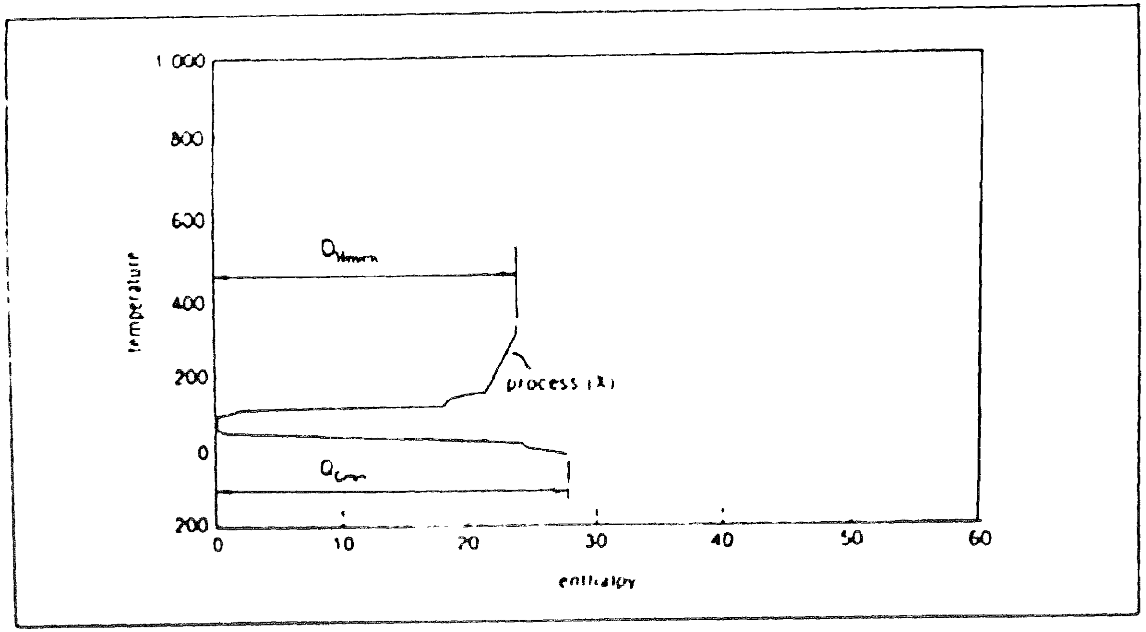
KTI A MANNESMANN COMPANY

HEAT INTEGRATION WITH NITRIC ACID PLANT - AN EXAMPLE

KTI

A MANNESMANN COMPANY

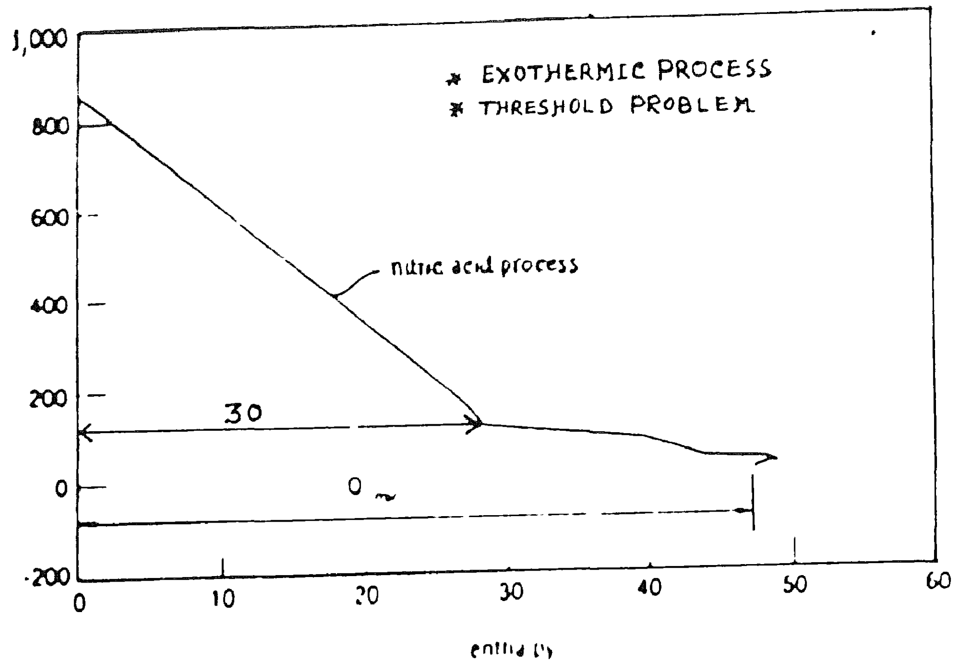
GRAND COMPOSITE CURVE OF ANOTHER PROCESS DOMINATED BY EVAPORATION DUTIES



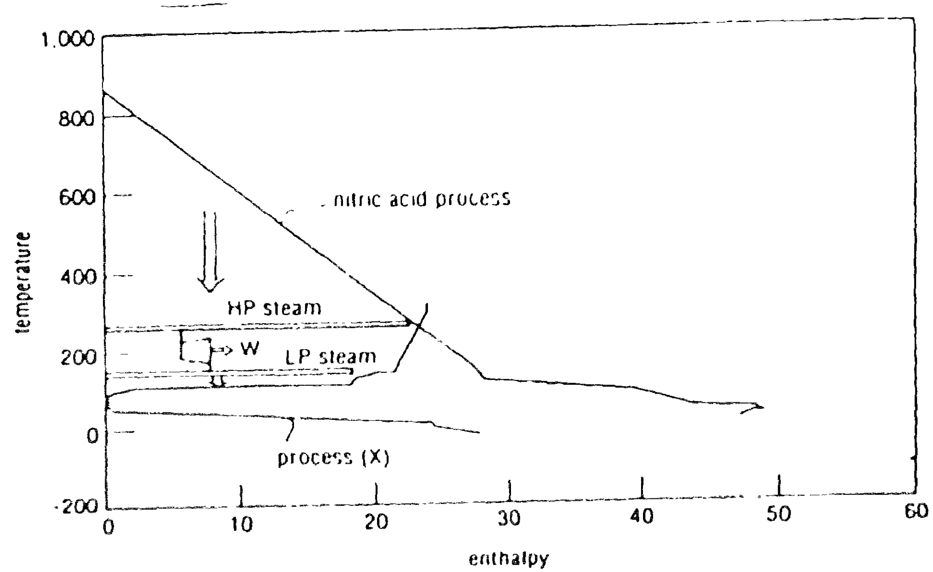
HOW DO WE INTEGRATE THE ABOVE WITH THE NITRIC ACID PLANT ?

KTI

Grand Composite Curve of Nitric Acid Process

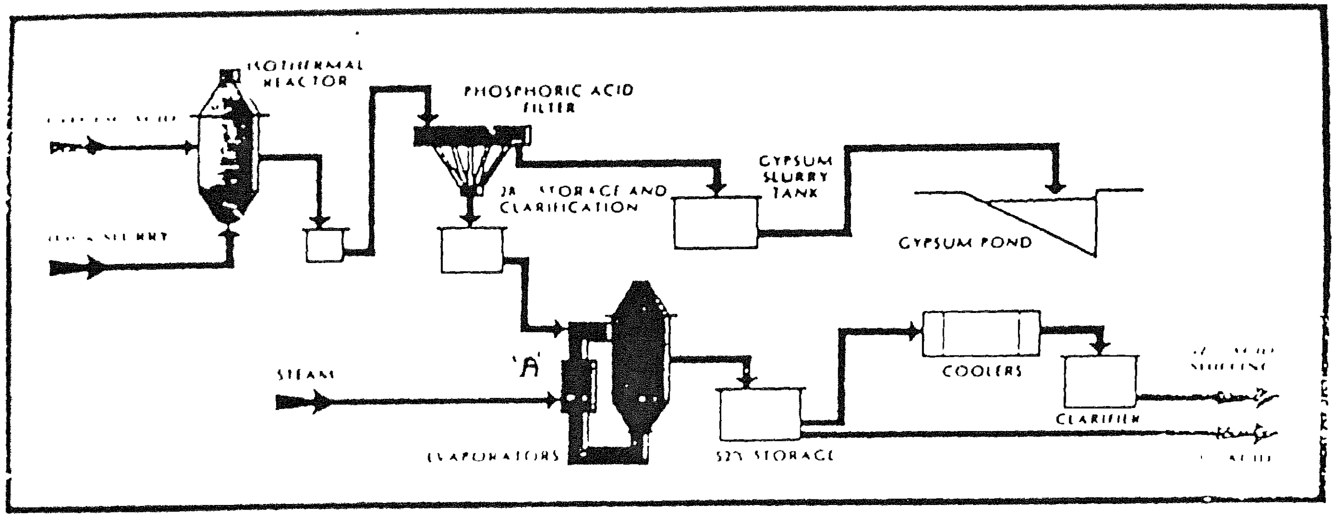


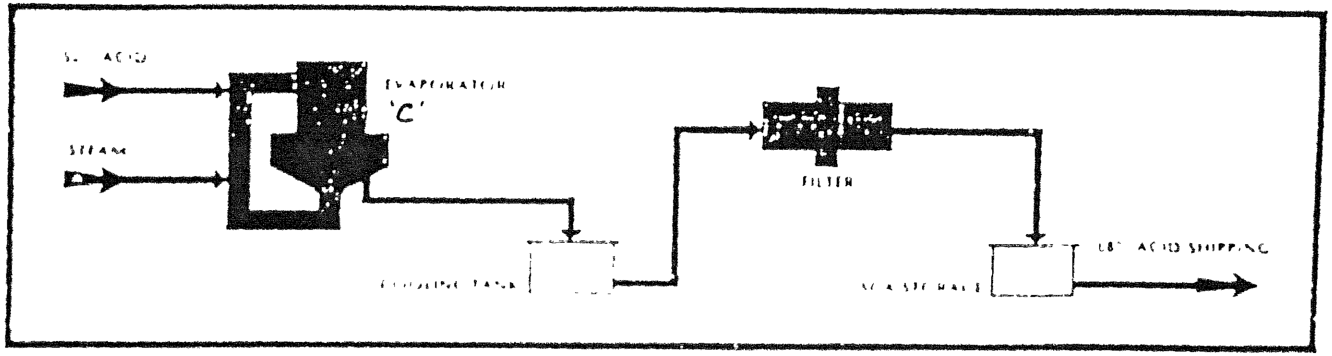
A POSSIBLE SCHEME BETWEEN NITRIC ACID PROCESS AND ANOTHER PROCESS



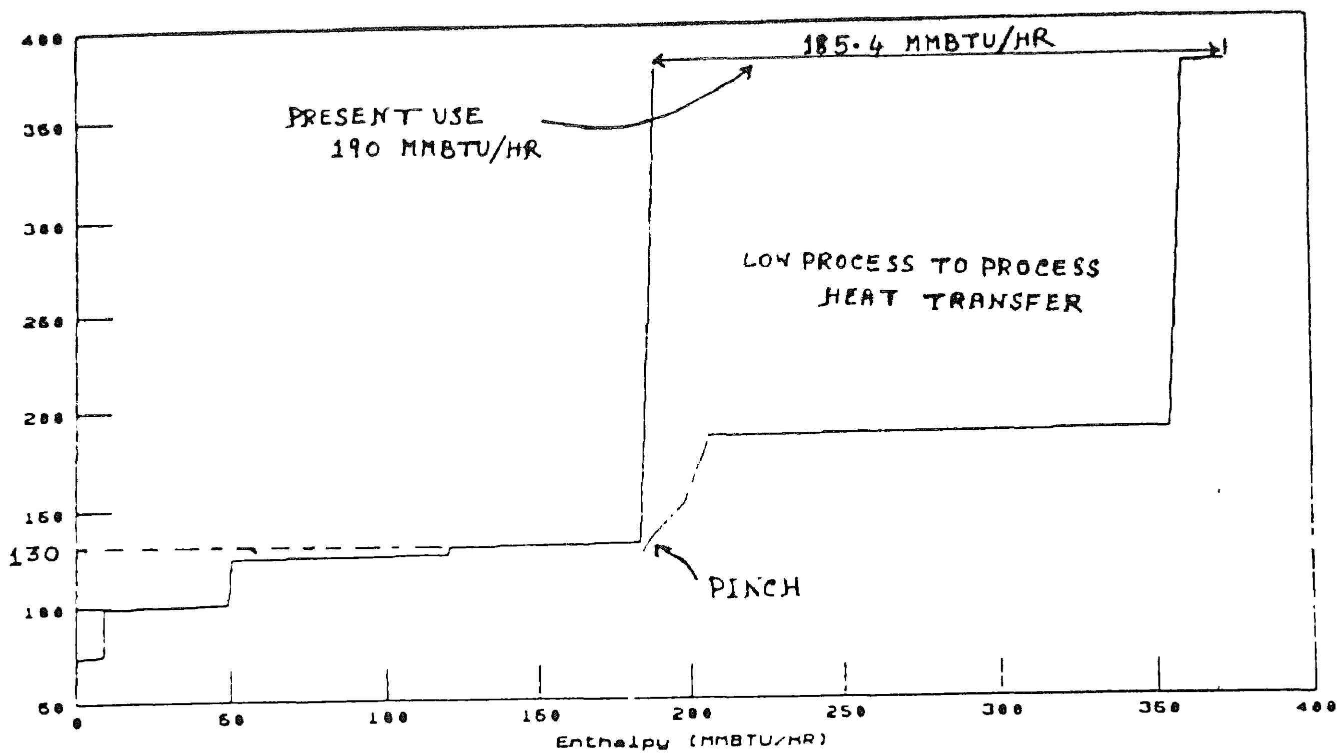
A MANNESMANN COMPANY

PHOSPHORIC ACID PLANT

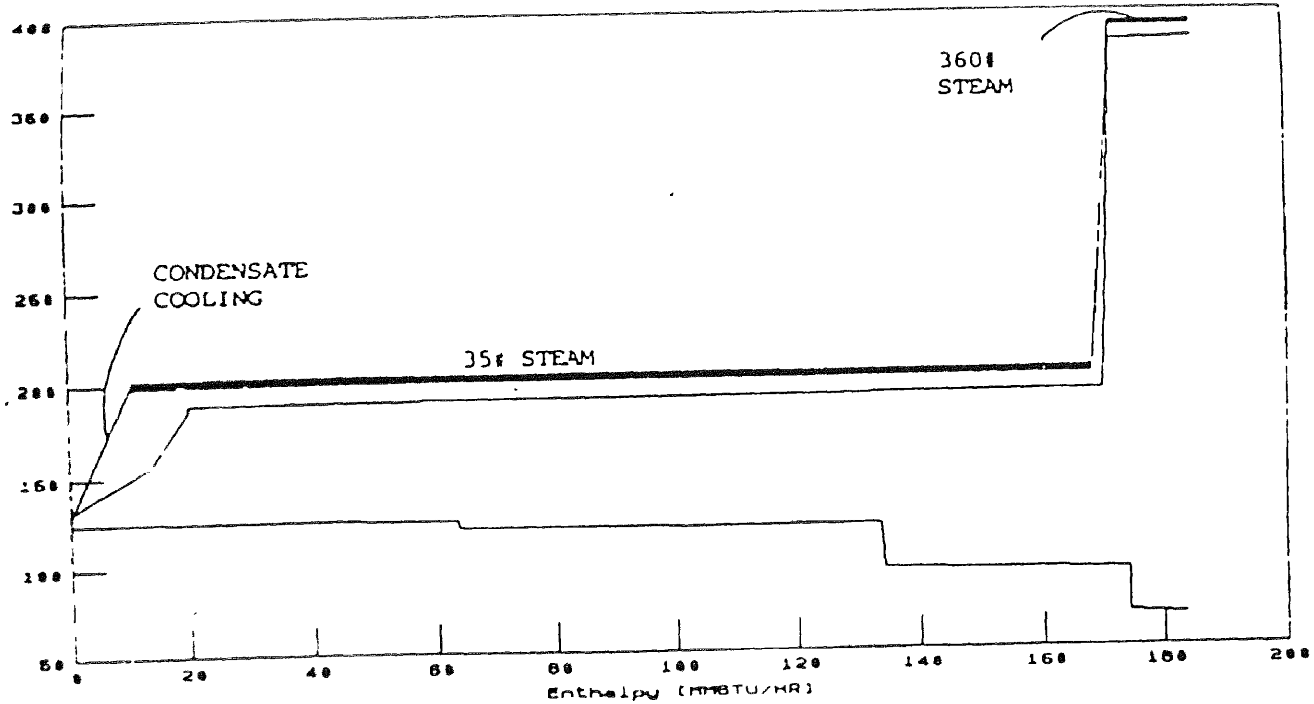




A MANNESMANN COMPANY



Composite Curves
Phosphoric Acid/Super Green Acid Plant



Grand Composite Curve
Phosphoric Acid/Super Green Acid Plant

- CHOICE OF UTILITIES
  - * 2.33 KG/ CM^2 STEAM : 71272.73 KG/HR
  - * 24 KG /CM^2 STEAM : 6272.73 KG/HR
- STEAM CONDENSATE IS COOLED DOWN TO THE 'PINCH' TEMPERATURE.

A MANNESMANN COMPANY

POSSIBLE MODIFICATIONS

1. RECOVER HEAT FROM 2.33 KG/CM^2 STEAM CONDENSATE BY COOLING TO PINCH TEMPERATURE - APPROXIMATELY 10 MMBTU/HR CAN BE RECOVERED

   TWO SCHEMES

   - PRODUCE HOT WATER FOR WASHING
   - PREHEAT FEED TO EVAPORATOR 'A', POTENTIAL TO INCREASE CAPACITY

2. HEAT RECOVERY FROM 69% ACID

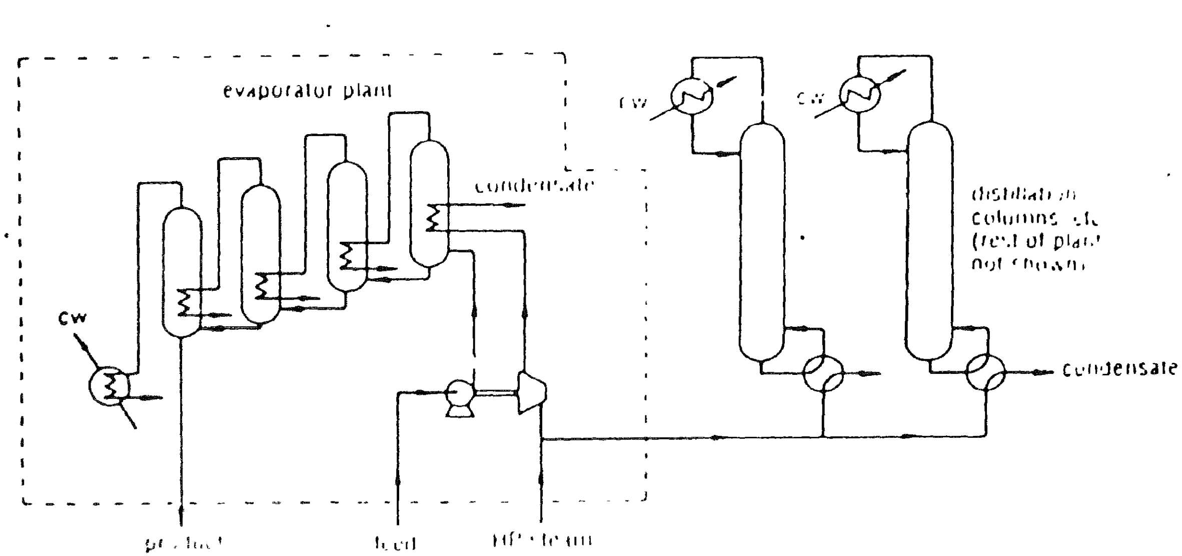
HEAT RECOVERY FROM 69% ACID

- SUPER GREEN PHOSPHORIC ACID PRESENTLY AT 377 ^{O}F COOLED TO 160 ^{O}F -HEAT LOST TO COOLING WATER
- APPROXIMATELY 4.1 MMBTU/HR CAN BE SAVED IN 24 KG/CM^2 STEAM IF 69% ACID STREAM FROM 'C' EVAPORATOR IS ALLOWED TO PREHEAT FEED TO 'C' EVAPORATOR.
- POTENTIAL TO INCREASE THE CAPACITY OF THE EVAPORATOR

KTI A MANNESMANN COMPANY

EVAPORATOR PLANT

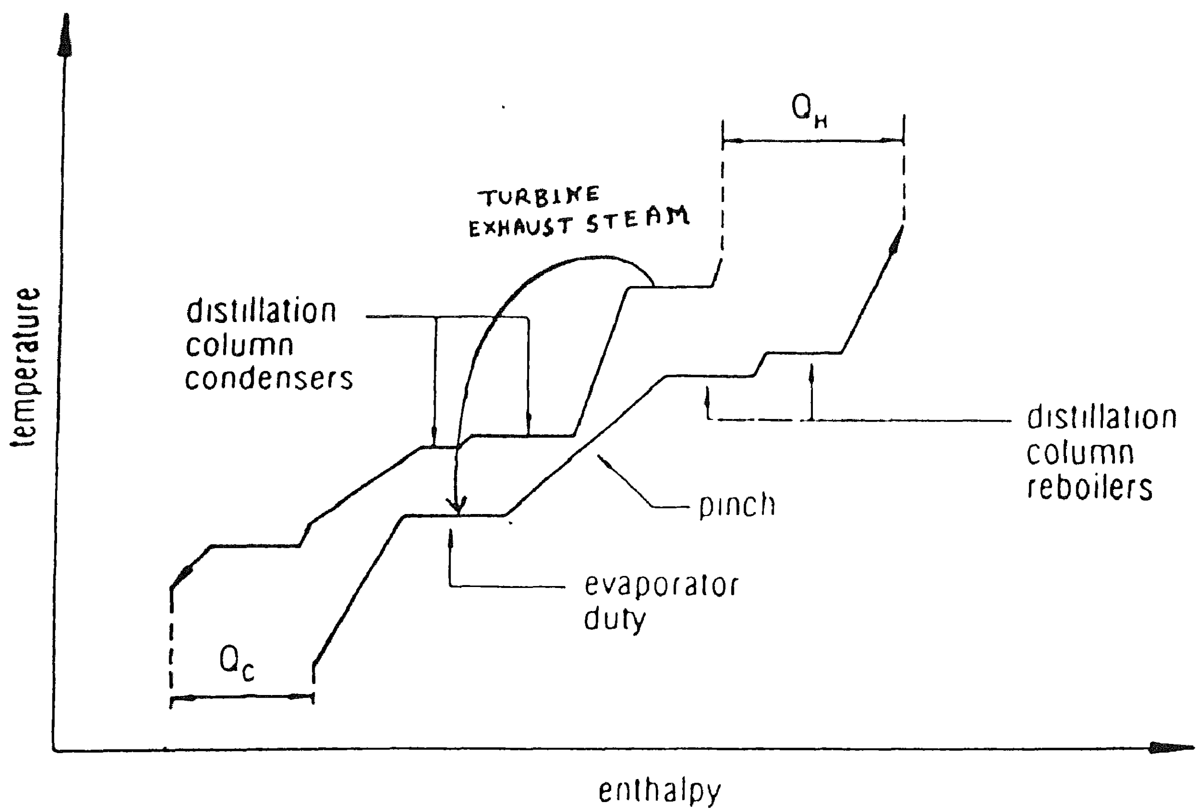
Existing Process

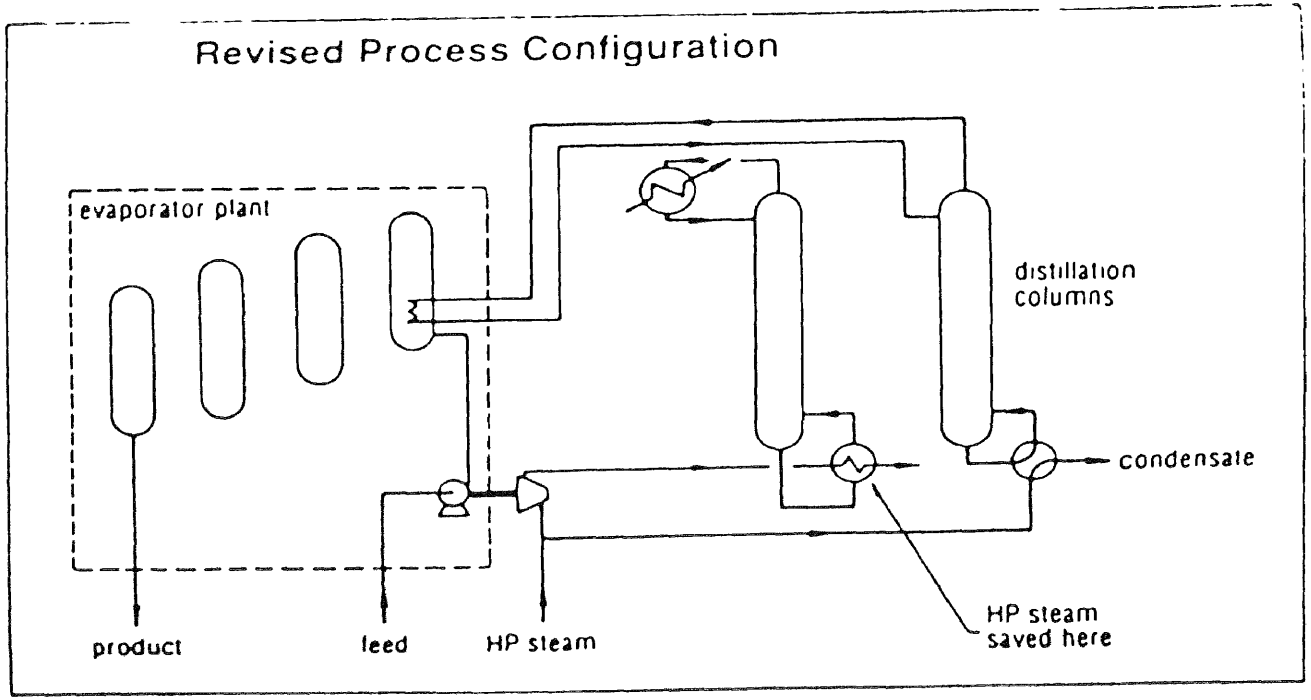


THE ABOVE PROCESS SEEMS TO BE A WELL INTEGRATED SYSTEM WITH LITTLE SCOPE FOR IMPROVE MENT

IS THIS TRUE ?

Composite Curves of the Existing Process





- THE ABOVE DEMONSTRATES NEED TO CONSIDER TOTAL SYSTEMS - THE ORIGINAL SCHEME OPTIMISED ONLY THE EVAPORATOR PLANT

CONCLUSIONS

- FERTILIZER INDUSTRY IS A LARGE CONSUMER OF ENERGY
- CONSISTS OF SEVERAL UNITS
- NEED TO OPTIMISE INDIVIDUAL UNITS
- LARGE INCENTIVES IN INTEGRATING THE ENTIRE COMPLEX
- PINCH TECHNOLOGY PROVIDES A SYSTEMATIC APPROACH FOR BOTH
  - OPTIMISING INDIVIDUAL UNITS
  - TOTAL SITE
- HEAT INTEGRATING TOTAL SYSTEM AS OPPOSED TO INDIVIDUAL EQUIPMENTS PROVIDES REAL SAVINGS

Pre-reformer the Solution for Increasing Plant Throughput

Pre-reformer,The Solution for Increasing Plant Throughput

Abstract

This paper describes the application of Pre-reformer in two decades old Ammonia plant Pre-reformer is a complete add-on unit installed to use naphtha as feed stock along with natural gas in the primary reformer . Pre-reformer can easily be isolated without any hindrance to the ammonia production from the rest of the ammonia plant Efforts are made to discuss the experience in the installation of pre-reformer system at IFFCO Kalol along with benefits achieved in overall productivity of Ammonia plant

1.0 Introduction :

IFFCO Kalol unit's original 910 tpd ammonia plant based on steam reforming of natural gas designed and supplied by M W Kellogg USA was commissioned in the year 1974 This plant was one of the largest single stream plant in the country during seventies and has been always a trend setter in the fertiliser industry Natural gas is used as feed stock and associated gas along with naphtha are used as fuel in the furnace Natural gas and associated gas are supplied by ONGC/GAIL from nearby gas fields in the vicinity of the plant and naphtha is supplied by IOC IFFCO has gas supply contract with GAIL for supply of 620000 Sm3/day natural gas and 220000 Sm3/day associated gas With the passage of time, the gas availability in the vicinity of plant is depleting and gas supply pressure has reduced from 40 kg/cm2g to 10 kg/cm2g over the period of 20 years The same has resulted into installation of booster compressors from 20 kg/cm2g to 40 kg/cm2g in 1984 and from 10kg/cm2g to 20 kg/cm2g in the year 1997 Because of low gas supply and reduced gas supply pressure, over-all productivity of plant is reduced

Higher capacity utilisation could not be achieved because of inadequate supply of natural gas Whenever natural gas was available, plant was operated at 110 to 115 % of rated capacity The figure - 1 shows the capacity utilisation of ammonia plant for last eight years

2.0 Why Pre-reformer Installation at IFFCO Kalol :

As a measure to improve the availability of feed stock and uprate the ammonia plant capacity from 910 tpd to 1100 tpd, it was decided to use naphtha as feed stock in addition to natural gas Use of mixed feed stock in primary reformer is not possible due to limited catalyst

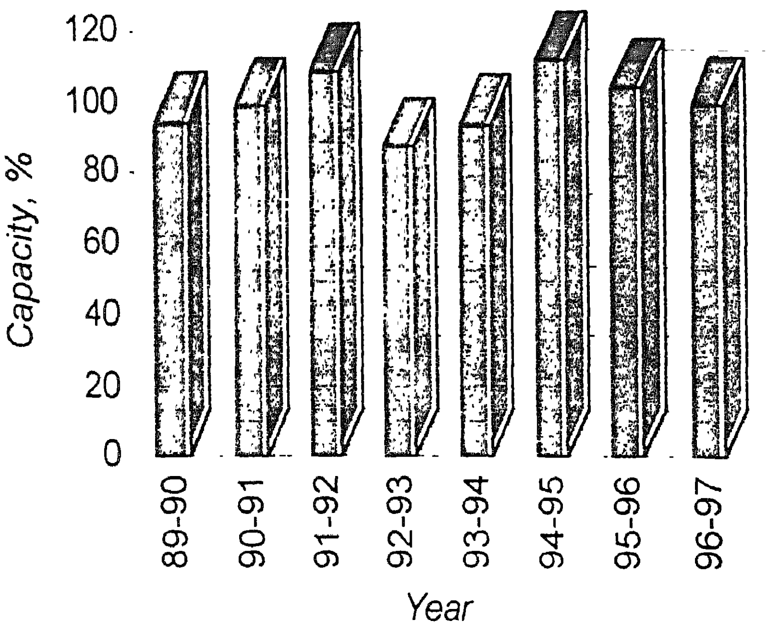
---

Mr. M.R.Patel
Sr.Manager (Process)
IFFCO Kalol

Mr. C.N.Shah
Manager (Process)
IFFCO Kalol

Mr. BPS.Mehta
Engineer (Process)
IFFCO Kalol

Ammonia plant capacity utilisation (figure-1)



volume of 17 7 m3 Also sufficient natural gas availability is a constraint for capacity enhancement, hence, it was planned for addition of pre-reforming system at upstream of primary reformer to use naphtha as feed stock In pre-reformer, naphtha is converted into H_2, CO, CO_2 and CH_4 in presence of highly active nickel catalyst at low temperature of 470 to 500 deg C About 25% of reforming duty is done outside the primary reformer at lower temperature, hence the heat duty of primary reformer is not increased proportionally for increased throughput with addition of pre-reformer unit

The Typical production and energy consumption figure before and after pre-reformer system is given in table-1

Table - 1 : Typical Production and Consumption Before and After Pre-reformer

DESCRIPTION			UNIT	BEFORE	AFTER
1 Daily Ammonia production			t/d	930	1080
2 Energy Consumption					
	Feed	Natural gas	Gcal/t	5 177	4 100
		Naphtha	Gcal/t	----	1 177
	Fuel	Associated gas	Gcal/t	1 858	2 016
		Naphtha	Gcal/t	1 954	1 993
3 Total			Gcal/t	8 989	9.286

3.0 PRE-REFORMING:

Pre-reforming is the term that has been applied to the low temperature steam-reforming of hydrocarbons in a simple adiabatic reactor. A wide range of feedstocks to the pre-reformer can be used, ranging from natural gas and refinery off-gases to butane and naphtha. The pre-reformer utilises the heat content of the feed stream to drive the steam-reforming reaction by the use of a highly active nickel catalyst which can promote the steam-reforming reactions at low temperatures. The pre-reforming reactions result in an equilibrium gas mixture containing hydrogen, carbon monoxide, carbon dioxide, methane and steam as per the reactions given below :

1.	C_nH_m	+	nH_2O ----->	$nCO + (n + m/2)H_2$		$H > O$ when $n > 1$
2	CO	+	$3H_2$ <===>	$CH_4 + H_2O$		$H = -206$ KJ mole
3	CO	+	H_2O <===>	$CO_2 + H_2$		$H = -41$ KJ mole

In the pre-reformer, the endothermic reaction is followed by the exothermic methanation and shift reactions, adjusting the chemical equilibrium between the carbon oxides, methane, hydrogen and water according to above reactions. The performance of Pre-reformer is directly reflected by the temperature rise/drop across the reactor depending on the type of feed. For typical natural gas feed, the overall process is endothermic, resulting in a temperature drop of about 25 to 30 deg C through the catalyst bed. For heavier feedstocks, such as naphtha, the overall process is exothermic, resulting in an overall temperature rise of about 15 to 20 deg C across the pre-reformer. The overall process is approximately theremoneutral with feedstocks such as propanes and butanes.

The specially precipitated, high-nickel catalyst is in the form of cylindrical pellets, has the high activity required for hydrocarbon steam-reforming reactions at low temperature. High activity also ensures that the feed gases are reacted to equilibrium, and high space velocities can be used. The catalyst formulation is such that carbon-forming reactions are avoided. For new catalyst, the outlet concentration of higher hydrocarbon should be negligible and constant. If pre-reformer outlet hydrocarbons starts to rise, the catalyst charge is considered deactivated. Deactivation of the pre-reforming catalyst is caused by impurities poison in the feed stream i.e. sulphur, alkali, silica and arsenic etc. The necessary catalyst volume for required life time depends on the type of feed and process conditions like temperature, pressure and S/C ratio. The reactor volume is typically designed for 2 to 3 years of operations.

3.1 PRE-REFORMING IN EXISTING AMMONIA PLANTS:

In a conventional ammonia plant steam-reforming system, the mixed feed gas and steam passes through a mixed feed coil in the steam reformer flue gas duct, and into the primary reformer catalyst tubes. The most effective way of integrating a pre-reformer into an existing ammonia plant steam reformer system is to connect the pre-reformer, a adiabatic reactor containing the highly active pre-reforming catalyst at the upstream of primary reformer. This reduces the reforming duty of primary reformer, which in turn result in a reduction in fuel requirement by 5-10%. Alternatively, the advantage can be taken by increasing the throughput of about 5-10%

The retrofitting of a pre-reformer into an existing ammonia plant can offer two principal benefits

i) the potential for increased plant throughput,
ii) increased flexibility in terms of the feedstock going to the steam reformer

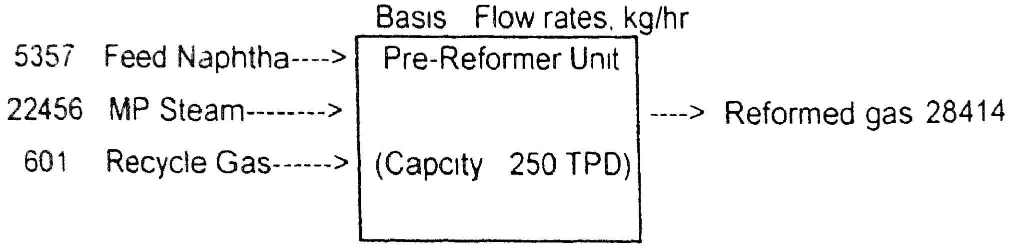
4.0 Pre-reformer system at IFFCO Kalol:

At IFFCO Kalol, pre-reformer system equivalent to 250 tpd ammonia production is a complete add-on unit and can easily be taken in and out of operation without obstructing the ammonia production from the rest of the ammonia plant M/S Haldor Topsoe is the main designer and licenser of Pre-reformer Unit. M/s PDIL was main Indian Consultant and M/s L & T Mumbai was main contractor for fabrication job at site. Naphtha pre-heater and superheater package erection and fabrication job was carried out by KTI New Delhi Mechanical completion of entire system was completed on August 20,1997 and system was commissioned in last week of August -1997 The design basis for the pre-reformer system are given in table -2 and design material balance of pre-reformer unit is given in figure - 2

Table - 2 : Design basis for Pre-reformer.

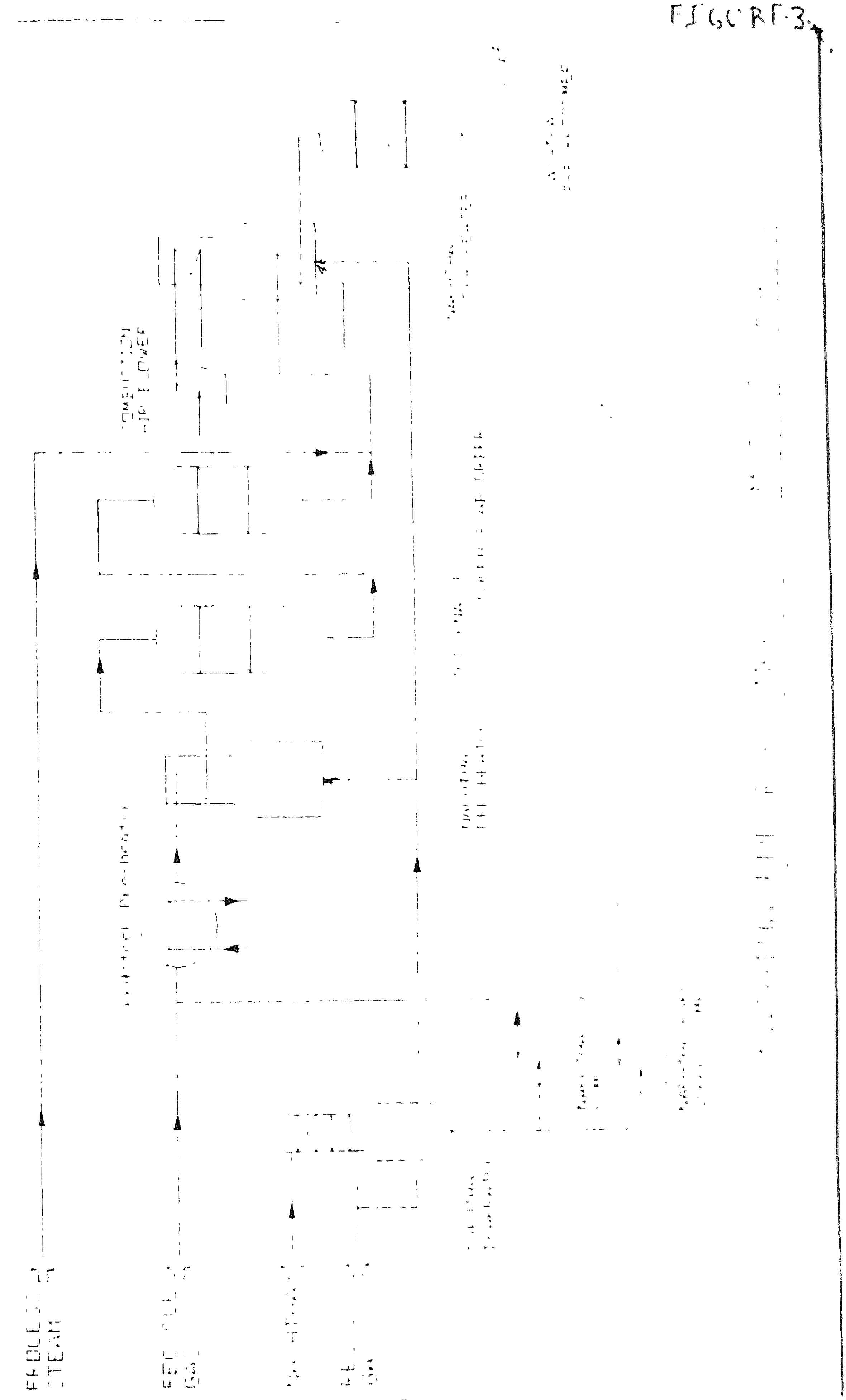
(a) Naphtha analysis				
1	IBP	Deg C	55	60
2	FBP	Deg C	180	160
3	Paraffin & naphthenes	% w/w	87.75	92.5
4	Aromatics	% w/w	12	5.5
5	Oleffins	% w/w	0.15	0.05
6	C/H ratio		5.5	5.5
7	Sulphur	ppm	100	150
(b) S/C mole ratio			3.3	3.3
(c) Aromatics in outlet gases		ppm	2000	100

Figure - 2 : MATERIAL BALANCE OF PRE-REFORMER UNIT.



Pre-reformer unit flow diagram is shown in figure - 3 Entire operation of pre-reformer is controlled by latest version of Distributed Control System (DCS) Details in brief of the different sections of pre-reformer unit are described here under

FIGURE 3.



4.1 Deaeration :

Naphtha is used as feed and fuel in ammonia plant Raw naphtha is first sent to deaerator packed with 1 27 m3 40 mm size SS - 304 pall rings Dissolved oxygen is removed by stripping with off gas from Purge Gas Recovery (PGR) unit Oxygen presence causes the gum formation in the heat exchanger, heaters, burners etc The enriched off gas from deareator is used as fuel in heaters in pre-reformer unit The deaeration takes place at about 1 6 kg/cm2g and deaerated naphtha is supplied as fuel to primary reformer and as feed stock to Pre-reformer

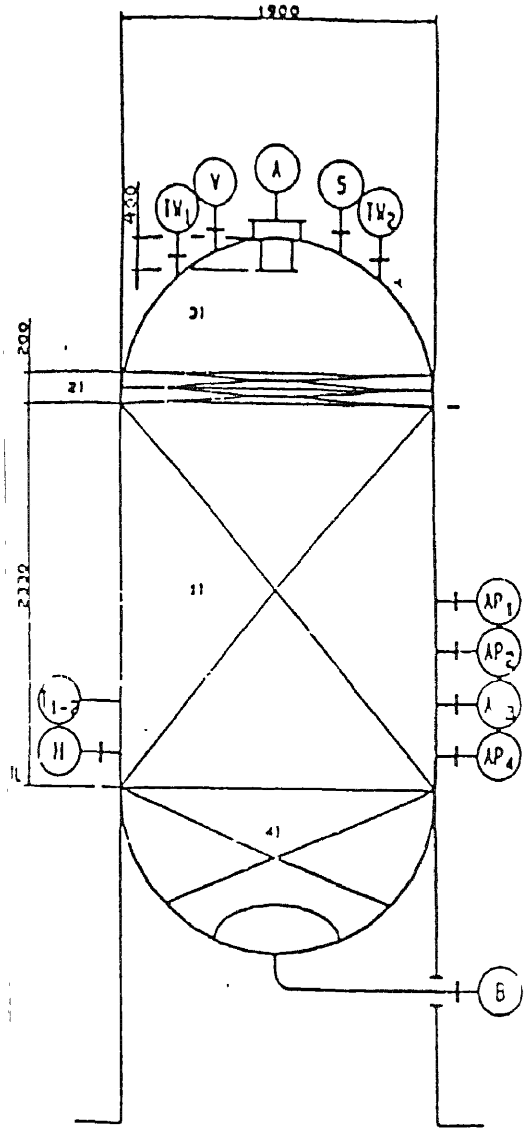
4.2 Desulphurisation

Desulphurisation takes place in two parts, hydrogenation and sulphur absorption In the desulphurisation process, catalytic hydrogenation of organic sulphur compounds is followed by absorption of the hydrogen sulphide on zinc oxide Sulphur compounds are poison to all the down stream catalysts like pre-reformer, primary reformer, shift converter and synthesis etc, therefore removal of sulphur compounds is essential Deaerated naphtha at a pressure of 43 kg/cm2g is mixed with recycle hydrogen and preheated to 125 deg C with LP steam in a heat exchanger and sent to naphtha pre-heater where naphtha-recycle hydrogen gas temperature is increased to 380 deg C befor passing through hydrogenator contaimg 3 2 m3

Co-Mo catalyst for converting organic sulphur compounds to hydrogen sulphide After hydrogenation, gas passes through the sulphur absorber containing 19 3 m3 zinc oxide catalyst to absorb hydrogen sulphide Sulphur contained in feed stock will be reduced to a very low level i e below 0 05 ppm by weight

4.3 Pre-reforming :

The desulphided naphtha coming from desulphurisation section along with surplus hydrogen is mixed with steam and heated to 490 deg C in pre-reformer feed preheater The mixture is sent to pre-reformer, an adiabatic chemical reactor containing 5 6 m3 nickel based catalyst as shown in figure - 4, which has reforming activity at low temperature All higher hydrocarbons will be completely converted to a mixture of H_2, CO, CO_2 and CH_4 This mixture is added to the pre-heated natural gas-steam mixture at the inlet to the primary reformer In pre-reformer temperature decreases in upper catalyst bed by about 15 deg C due to endothermic reaction and followed by a temperature rise of about 31 deg C due to exothermic reactions i e methanation and shift reaction Thus the net results is temperature increase of about 16 deg C Actual temperature across pre-reformer is shown in figure-5 and details of design and guarantee test run data of pre-reformer system are given in table-3



OPERATING/MECHANICAL DATA

Fluid	NAHTHA/HYDROGEN/STEAM	Units
Liquid: quantity		kg/h
density		kg/m³
Gas: quantity	39772	kg/h
molecular weight	20,66/18,18	
density	12,4/10,4	kg/m³
Operating temperature	490/505	°C
Operating pressure	36,5	kg/cm² g
Volume: total		m³
Design temperature	535	°C
Design pressure	44	kg/cm² g
Test pressure		kg/cm² g
Shell id	1900	mm
Catalyst bed height	2330	mm
Height of skirt		mm
Corrosion allowance	1	mm
Shell thickness		mm
Insulation thickness	YES	mm
Shell material	2 1/4 Cr 1 Mo	
Construction code	ASME Sec. VIII Div. 1	
Stress relieving	Acc. to code	

REF.	NO	SIZE	FUNCTION
A	1	20"	GAS INLET (ALSO MANHOLE)
B	1	14"	GAS OUTLET
H	1	16"	HANDHOLE; INTERNAL LID; 7)
AP1-4	4	2"	ANALYSIS POINT
TW1-2	2	2"	THERMOWELLS
T1-2	2		SURFACE TEMPERATURE ELEMENTS
V	1	2"	VENT
S	1		SAFETY VALVE

FIGURE- 4

PRE-REFORMER

Temperature profile of Pre-reformer using Naphtha as feed (figure-5)

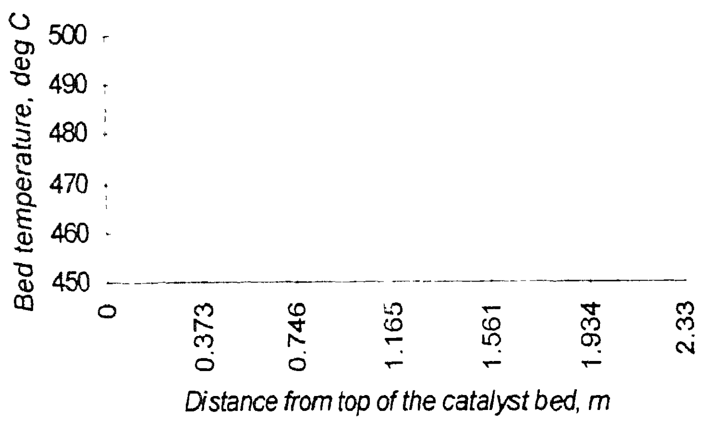


Table-3 : Naphtha pre-reformer design and guarantee test run

Sr. No.	Description	Unit	Design	Guarantee Test Run
1.	Ammonia production	tpd	250	268
2	Feed naphtha flow	t/hr	5.356	5 831
3	Naphtha Pre-heater duty	Gcal/hr	1 25	1 554
4	Naphtha super heater duty	Gcal/hr	3 15	4 21
5	Process steam flow	t/hr	22 47	23 18
6	Electric Power	kwh	15	35 65

4.4 Naphtha recovery system :

No hydrocarbon vapors are allowed to vent into atmosphere Naphtha condensation system is installed as a part of pre-reformer system It consists of an air-cooled heat exchanger, separator and two naphtha pumps All vents are routed through the naphtha condensing system This system remains in line during start-up, tripping of pre-reformer unit and safe shut down of the plant All hydrocarbons vapor are condensed and collected in separator before routed to flare system Separated naphtha is recycled back to deaerator

4.5 Vents and Flare stack :

As a measure to vent the gases during start up, shut down and during plant upsets or emergencies, vent header connected with 15 different vent points/relief valve outlets along with flare stack and associated system are provided to avoid venting of hydrocarbons and other explosive gases to atmosphere

5.0 Constraints and problems faced:

The details of several problems / constraints faced are given below

- The sulphur absorber catalyst volume of 19.3 m3 is provided for 2 to 3 years of catalyst life with 100 ppm sulphur present in the feed stream. High sulphur in feed naphtha is one of the main constraint. Higher sulphur in feed naphtha will require faster replacement of catalyst in sulphur absorber.

- Pre-reformer system is designed for 12 % aromatics in feed naphtha with maximum flexibility to operate up to 18 % aromatics with aromatic slip of about 2000 ppm by vol. Higher aromatics slip will damage the primary reformer catalyst and will increase the pressure drop in primary reformer.

- Pre-reformer system trips during power failure. After resuming power supply, pre-reformer system is lined-up at ammonia plant. With tripping of pre-reformer, air in secondary reformer for H2 / N2 ratio control and primary reformer fuel firing for furnace temperature control are required to be reduce immediately.

- Initial startup was slightly delayed due to limitation of final vent control valve at exit of pre-reformer. During startup, system pressure remain in the range of 5-6 kg/cm2g. Control valve Cv is calculated based on normal operating system pressure of about 36.2 kg/cm2g. Therefore, system pressure was slightly increased to remove the bottleneck.

- The control valves on MP steam to naphtha and recycle hydrogen to naphtha had some problem and by-pass valve of the control valve were opened to maintain the flow.

6.0 Benefits of pre-reformer system :

The benefits achieved by installation of pre-reformer unit are given below

- Increase in throughput of the plant with use of naphtha as feed from 850 - 900 t/d to 1100 t/d. Also plant will run at constant load, leading to smooth operation and better optimisation of plant parameters.

- Reduction in severity of furnace firing of the primary reformer furnace at similar plant load. This has increased flexibility in primary reformer for higher load operation.

- Choise for use of feed stock i.e either natural gas or naphtha when surplus gas is available.

- There will be improvement in life of primary reformer catalyst due to presence of H2 in feed gas to primary reformer from pre-reformer.

- The S/C ratio at the inlet of primary reformer can be reduced to 3.3 against 3.5 for original plant. This will reduce energy consumption by 0.1 Gcal/t ammonia.

6.0 Conclusions :

Ammonia manufacturing is highly energy intensive and has presented a real challenge to industry for past many years. The conventional steam-hydrocarbon reforming takes place at temperature of 800 to 810 deg C The concept of Pre-reformer is in essence that a portion of the primary reformer duty is done outside of the conventional primary reformer The application of pre-reformer enables the hydrocarbon -steam reforming at low temperature and also ensure that feed gases are reacted to equilibrium. With the installation of pre-reformer, IFFCO' objectives are fulfilled as given below :

- Increasing ammonia plant capacity from 910 t/d to 1100 t/d.
- Increasing flexibility for use of feed stock i.e. either naphtha or natural gas when surplus gas is available
- Increasing the flexibility in operation of primary reformer

Looking to the IFFCO Kalol unit's experiences, pre-reformer can be useful for gas base ammonia plants where gas availability is a constraint for higher plant load operation and naphtha based plants where primary reformer is a limiting factor